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The American Journal *of* Physiological Optics

A QUARTERLY JOURNAL

Edited by

CHARLES SHEARD, PH.D.

VOLUME III

1922

Published by the Division of Ocular Interests
American Optical Company

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Entered as second-class matter January 20, 1922, at the post office at Southbridge. Mass., under the Act of Congress of March 3, 1879

V

American Journal of Physiological Optics

Volume III, 1922

INDEX

VI

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2

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JANUARY 1922

Volume III Number 1

Published by the Division of Ocular Interests

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3

DIOPTRICA NOVA.

A
TREATISE
OF
DIOPTRICKS,
In Two PARTS.

Wherein the
Various Effects and Appearances
OF
Spherick Glasses,
BOTH
Convex and Concave, Single and Combined,
IN
TELESCOPES and MICROSCOPES,
Together with
Their USEFULNESS in many Concerns of Humane Life,
ARE EXPLAINED.

By WILLIAM MOLYNEUX of *Dublin* Esq;
Fellow of the ROYAL SOCIETY.

Ex Visibilibus Invisibilia.

London: Printed for BENJ. TOOKE, MDCXCII.

The American Journal *of* Physiological Optics

William Molyneux and his *Dioptrica nova*

Charles Sheard, Ph. D.

NOT so very long ago a friend, who is very much interested in the field of optics and in its application to the preservation and conservation of vision, handed us an old, time-stained and scarred sheepskin volume with the query: Did you ever hear of Molyneux and have you ever seen the original or any excerpts from *Dioptrica nova?* We confessed that we should have to answer in the negative in each particular—and immediately sat down to find some of the treasures contained within the covers of the book proffered.

To be sure, we should not recommend Molyneux's *Treatise of Dioptricks* as a twentieth century manual upon optics. To the hard-headed, practical individual who cares for nothing except an answer to his immediate problems and to that individual who is interested not at all in the records of the past and in the men and things of the by-gone days and who has nothing of the spirit of "hero-worship" within the soul, doubting that man was created in the image of God—to such individuals those stained and yellowed pages of 1692 would strike no chord of response. But most of us, thank Heaven, are believers in *men*, both of yesterday and today; most of us, interested in the broad field of physiologic optics, not only desire the latest work applicable to our science but we also wish to see and to handle the works of the masters, not revised and reprinted, but as they themselves held them in their own hands and viewed them with

their own eyes. We cannot express to the reader the pleasure and the profit afforded by the hours spent with Molyneux and his English treatise on optics. In lieu of this, however, we can present a few of the interesting passages, and in particular give to you in the pages of this *Journal* photographic reproductions of the title-page of *Dioptrica nova* and of the chapter: *Of Glasses for Defective Eyes.*

In the first place, then: What of William Molyneux, of Dublin, Esq.; Fellow of the Royal Society? An examination of the sources directly at our elbows has told us but little. We do not remember to have seen his name recorded in the History of Ophthalmology by Dr. Shastid as published in the eleventh volume of the *American Encyclopedia of Ophthalmology*, and that doubtless for the reason that he is classed amongst the astronomers. But we discover some account in the *Encyclopedia Britannica* and read: "Another Molyneux family of some importance is the Irish one, descended from Sir Thomas Molyneux (1531-1597), Irish chancellor of the exchequer, who, born at Calais, settled in Ireland in 1576. He was the great-grandfather of Sir Thomas Molyneux, Bart. (1661-1773), a well-known physician and zoölogist, and of William Molyneux (1656-1698), the philosopher, astronomer and politician, the friend of Locke and author of *Dioptrica nova* (1692), whose famous work on the legislative independence of Ireland (*The Case of Ireland*, 1698) created much stir at the time." The *Encyclopedia* has evidently enlightened us as to the "why and wherefore" of the paragraph Molyneux inserted on page 258 of the *Dioptrica nova*, in which he writes: "I Confess, I have not by me at this time the originals, from whence these Passages are quoted; the present Distractions of our miserable Country having separated me and my Books; and the Place where I am, affords not the Copies: Therefore, if in these *Quotations* I am any wise mistaken, I must not be blamed." In these days men and women are rarely forcibly separated from their books: rather are they too

rarely found in their company. The real lover of his books can appreciate with what genuine sorrow Molyneux must have penned that paragraph. And, too, the philosophers, astronomers and politicians of 1921 have not seen the solution of some of the problems that taxed the brain and shortened the life of the philosopher, astronomer and politician of the pages of *Dioptrica nova* of 1692.

And now, as to the *Treatise of Dioptricks*. On the fly-leaf, facing the title page, as an expression of commendation to us, we find these words: "I think this Book fit to be Printed: (Dated) June the 4th, 1690; (Signed) John Hoskyns, V. P. R. S." Surely all of us can appreciate how inwardly pleased and honored Molyneux must have felt in receiving the commendation of the highest scholastic body in the world of that day.

An eight-page dedication—*To the Illustrious, The Royal Society*—follows the title page. This is of a philosophical character, centering largely around the thought that any scientific discovery adds one link more to the chain of natural causes and that no one should mistake the single link for the whole chain. In closing his Dedication he writes: "I beg Pardon both for this Digression and for telling you Things which you very well know already." Hardly did he or does anyone today need to beg pardon for retelling to us things we ought to know; for homely facts, dressed up in new garb, catch our mind's eyes and charm our mental selves.

Like all men of ability we find that Molyneux admitted his liability to error and declares: "That if in anything hereafter delivered, I have made any Mistakes, or not so clearly expressed myself upon Intimations thereof, I shall be most ready to retract. * * * *Humanum est.*"

Furthermore, we are acquainted with the fact that the volume is the first of its character to be written and published in English. He writes:—"Tho I had begun and made some Progress in this Work in *Latin;* yet I thought it convenient

to alter my Design: There being nothing in this *Part* of *Mathematicks* ever yet publish'd in *English*." A survey of the data as to dates of publication and as to their presentation in English or Latin apparently supports Molyneux's contention. For we find that 1704 marks the appearance of the first (English) Edition of Sir Isaac Newton's Opticks or "*A Treatise on the Reflections, Refractions, Inflections and Colours of Light*." And Molyneux further comments: "And I am sure there are many ingenious Heads, great Geometers, and Masters in Mathematicks, who are not so well skill'd in *Latin*." Evidently Latin was cussed and discussed in those days and many brilliant minds knew not the Latin.

As we thumb through the sheets of this volume we find that nearly two hundred pages are devoted to a discussion of fifty-nine propositions in *Dioptricks*, covering reflection, refraction, thick and thin lenses, convex and concave forms, and the character of the vision obtained through them under various conditions. Reading at random through the book we come to Prop. XXVIII entitled: *The manner of Plain Vision with the naked Eye is expounded.* The remarks upon the manner of accommodation are of interest as expressing an opinion held in days prior to the researches of Thomas Young in 1801—and even Young was ignorant of Bruecke's and Mueller's muscles and of the actual modus operandi of accommodation. Incidentally, none of us know just *how* accommodation in all its details takes place in the human eye. Molyneux writes: "'Tis therefore contrived by the *Most Wise and Omnipotent Framer of the Eye*, that it should have a Power of adapting itself in some measure to Nigh and Distant Objects. For they require different Conformations of the Eye; Because the Rays proceeding from the Luminous Points of Nigh Objects do more Diverge, than those from Remote Objects.

"But whether this variety of Conformation consist in the Crystallines appearing nigher to, or removing farther from the *Retina;* or in the Crystallines assuming a different

Convexity, sometimes greater, sometimes less, according as is requisite, I leave to the scrutiny of others and particularly of the curious Anatomist. This only I can say, that either of these Methods will serve to explain the various Phaenomena of the Eye; And I am apt to believe, that both these may attend each other." So we find that Molyneux admitted the possibility of changes in crystalline curvature which Thomas Young demonstrated to be the case a little over a hundred years later. And the "curious" anatomists did not discover the two sets of fibres in the ciliary muscle till the lapse of a century and a half following the appearance of *Dioptrica nova.*

And in this same discussion upon the manner of vision we find some digression upon the matter of inverted retinal images and the perception of objects as erect. "And here it may be enquired; How, then, comes it to pass that the eye sees the object *Erect?* But this Quaery seems to encroach too nigh the enquiry into the manner of the Visive Faculties Perception; For 'tis not properly the Eye that sees, it is only the Organ or Instrument, 'tis the *Soul* that *sees* by means of the Eye. To enquire then, how it comes to pass that the Soul perceives the *Object Erect* by means of an *Inverted Image*, is to enquire into the Souls Faculties." But, as he says, "to offer at something," *erect* and *inverted* are only terms of relation to *up* and *down* or further *from* and *nigher* to the center of the earth. He continues: "Hereof we may be satisfy'd by supposing a Man standing on his Head: For here, tho the Upper Parts of objects are painted on the Upper Parts of the Eye, yet the objects are judged to be *Erect.* And from this Posture of a Man, the Reason appears why we have used the Words *Farthest from*, and *Nighest to the Center of the Earth*, rather than *Upper* and *Lower.* For in this Posture, because the Upper Parts of the object are painted on that Part of the Eye nighest the Earth (though really the Upper Part of the Eye), they are judged to be farthest removed from the Earth." He returns

to this subject on page 212, and this page is included in those reproduced for your perusal. And after all is said and done, Molyneux's explanation of over two hundred years ago is as satisfactory in essentials as any we possess.

Astigmatism, *per se*, was not known in the days of Molyneux. On page 211 (reproduced herewith) of his treatise we find that he knew that eyes were "so ill-conformed" as to be relieved by no form of lenses then known. For astigmatism was first discovered by Thomas Young, who, in the *Philosophical Transactions* for 1793, published an account of the asymmetry of his own eye and attributed it to an oblique position of his lens. His account, by the way, is so accurate that we infer it would have been corrected by a —1.75 cyl. ax. 90° and that this would be induced by a 15° rotation of his crystalline lens round its vertical axes. His astigmatism was peculiar in that it was of lenticular origin, for it still persisted when his eye was plunged in water. It was not until 1827 that the astronomer Airy corrected his defective sight by means of cylindrical lenses, and since that time spectacle lenses for various purposes have been so accurately made that simple errors of refraction may be discovered and compensated.

To us, one of the most interesting parts of the whole volume consists of the various proofs offered to show that, "Light is a Body." By way of introduction, it should be recalled that this treatise was penned and printed at the time the astronomer Roemer demonstrated—"by the immersions and emersions of the Satellites of Jupiter," as Molyneux refers to them—that light travels about 186,000 miles a second; that the king of all scientists, Sir Isaac Newton, had written his *Principia* and was about to issue his *Dioptricks* and that he held to the emission theory of light; that Huyghens had laid the foundation for the undulatory theory of light only to be overruled until the days of Young and Fresnel; that such illustrious men as Hally, Flamsteed and Scheiner were contemporaries. That light is a body was the accepted

doctrine in 1692, to be supplanted about a hundred years later by the wave theory, only to see in these early days of the twentieth century the quantum and relativity theories, with proofs of the existence of electrons and discrete units of energy, all of which are tending to carry us back, in part at least, to the old tenets. In brief, Molyneux's three arguments in favor of the proposition that "light is a body" are: (1) That light is refracted and hence "in its passage through this and t'other diaphanous body" encounters a different *resistance*. "'Tis manifest," he writes, "that Resistance must proceed from *Contact* of two *Bodies* and *Contact*, either *Active* or *Passive*, belongs only to Body." (2) That light is a body because it requires time to pass from one place to another, "and does it not in an *instant*, but is only of all Motions the *quickest*." (3) "That it cannot by any Act or Contrivance whatsoever be *increased* or *diminished;* that is to say, we cannot magnifie the light of the Sun or a Candle, no more than we can magnifie a cubick inch of Gold, or make it more than a Cubick Inch."

The volume as a whole abounds in various digressions of a philosophical character. At heart Molyneux was a reasoner about things here and hereafter; by nature he was a philosopher of the natural and supernatural. Possibly no passage illustrates his digressions into the realm that is real but uncharted, than his remarks upon *Designs* and *Final Causes*. And whether we agree or disagree with these side-journeys is of no consequence; it is a delight to have the clean-cut facts of natural philosophy interspersed with views as to the ultimate ends and aims of Nature. So he writes (page 195): "Indeed I should think it an Attempt worth the Thought of some profound Philosopher, to give an Account of those admirable, orderly, and beautiful Appearances in Nature, whereof we can most plainly apprehend the *Designs and Final Causes*, but can hardly proceed to any farther *knowledge* of them. (Thus for instance, suppose it were asked, *What is the cause of Refraction?* Were it not much

satisfactory to answer, *That thereby the Ray may proceed the easiest way possible.*) This surely might be able to convince the most obstinate Opposers of *Divinity:* For certainly, if we can rely upon any *Deduction* or *Consequence* drawn out by the *Mind of Man*, we may assuredly rest satisfied in this; that so many Phaenomena, stupendous and surprising for their *designed Contrivance* could not proceed but from an *Omnipotent* and *Designing Being*. But if after all, they will arrive at such a height of Extravagance, as to say, We cannot rely on these Conclusions as being *all* in the *dark* and knowing nothing; let them look to the hazard of their own Principles, who endanger their *enternal Happiness* on confidence of their own *Arguments*."

And characteristically of such logical minds, being appreciative of his side-journeying into other fields than those of *Dioptricks*, he concludes the paragraph we have just quoted with the sentence: "But to resume our Subject." Throughout the second part of the book in particular do we find these short excursions concluded—as he switches back on to the main track—with the remark: "But I beg Pardon for this Digression, in which I am thus engaged before I was aware." In our own college days we had a professor who often allowed us to ramble away from the main topic of discussion in so far as the lesson for the day was concerned. Off we would wander in perfect delight and sheer forgetfulness of anything but the joy of that which was being unfolded to our view. And suddenly, as we were drifting on and on, rising higher and higher, having all but left these mundane quarters, with souls fairly freed from human prison walls, there would come a moment's pause, the snap of a pair of fingers, the rasping of a chair as it was hitched over the floor. Yes,—and the voice of the professor, in a cold matter-of-fact sort of way but with infinite kindness in his tones, would bring us back home as he applied the mental brakes:—"Well,—to return to the crow." We have passed out from under his loving instruction and he has passed on

to be numbered with his fathers, but ofttimes there comes to us the pleasant recollection and memory of the times we had "left the crow" and we have happily long since forgotten what happened when we returned "to the crow." We are sure, if you have any such combination of soul, mind and body, that you would love to read the last half of this old volume.

And there are occasionally touches of subtle wit and humor, and we may well imagine that, in his conversations with friends and in his "political" discourses, there was a keen and ready answer, with the ability to mingle the sobriety and seriousness of life with a twinkle of the eyes and a smile of the lips, and to turn tragedy into comedy and everyday life. To illustrate: After recording the fact that "Galileo is deservedly reputed the first that raised up this *Gigantic* Instrument (*i.e.* telescope), that ventures to climb Heaven and from thence bring down the Stars" and telling us "of the *four little Moons* dancing round *Jupiter*, that from their first creation to the lucky Moment when he (Galileo) first discovered them, had never struck the eye of any mortal Inhabitant of this Globe," we find Molyneux digressing from stars and telescopes, to imaginings with reference to "intelligent Beings" and "inhabitants of those distant Worlds." And finally he brings us back with infinite care and leaves us with a laugh in our hearts, and not to open abandonment and hopelessness, as he tells us: "But in this stupendous Inquiry I stop, as not being able to reach it with the *longest Telescope*." And yet one of the greatest philosophers of all time—possessed of no telescope, either large or small, long or short—could write: "For now we see through a glass, darkly; but then face to face: now I know in part; but then shall I know."

And as we close this little sketch of what we believe to be the real Molyneux and the worth of his labors, we pass you on to the chapter *Of Glasses for defective Eyes* as it is reproduced in the pages which follow, together with an expression

of our opinion that the opening eulogy on the Use of *Dioptricks* as helps for defective eyes clearly portrays to us the beauty of the mind and soul of William Molyneux of Dublin, Esq.

Chap. III.

Of Glasses for defective Eyes.

(1.) *Spectacles for old and pur-blind Men an Invention in Dioptricks of great use.* (2.) *Some Rules for choosing Spectacles both for old and pur-blind.* (3.) *Observations on Mr.* Hook's *Invention for helping* Myopes *by Convex Glasses.* (4.) *Telescopes and Microscopes adapted to defective Eyes.*

(1.) WEre there no farther Use of *Dioptricks* than the Invention of *Spectacles* for the Help of defective Eyes; whether they be those of *old Men*, or those of *pur-blind Men*; I should think the Advantage that Mankind receives thereby, inferiour to no other Benefit whatsoever, not absolutely requisite to the support of Life. For as the *Sight* is the most noble and extensive of all our Senses; as we make the most frequent and constant use of our Eyes in all the actions and concerns of human Life; surely that Instrument that relieves the Eyes when decay'd, and supplies their Defects, rendring them useful, when otherwise almost useless, must needs, of all others, be esteemed of the greatest Advantage. In what a miserable condition do we count those, in whom it hath pleased the *great Contriver of the Eyes and Sight*, to shut those two little Windows of the Soul? And we may imagine, that they, in whom these Lights are but *partly* obscured, do in some measure partake of the Misery of the blind. How melancholy is the condition of him, who only enjoys the Sight of what is immediately about him? With what Disadvantage is he ingaged in most of the Concerns of human Life? Reading is to him troublesome, War more than ordinary dangerous, Trade and

Spectacles for old and pur-blind Men, an Invention of great use.

Condition of old Men deplorable without Spectacles.

and Commerce toilſome and unpleaſant. And ſo likewiſe, on the other hand; How forlorn would the latter part of moſt Mens Lives prove, unleſs *Spectacles* were at hand to help our Eyes, and a little form'd piece of Glaſs ſupply'd the Decays of Nature? The curious Mechanick, engaged in any minute Works, could no longer follow his Trade than till the 50th. or 60th. Year of his Age: The Scholar no longer converſe with his Books, or with an abſent Friend in a Letter. All after would be melancholy Idleneſs, or he muſt content himſelf to uſe an other Man's Eyes for every Line. Thus forlorn was the ſtate of moſt *old Men*, and many *young*, before this admirable Invention; which, on this very account, can never be prized too highly.

Rules for Choosing Spectacles both for old and pur-blind. (2.) And becauſe in the Firſt Part hereof, *Prop.* XXVIII. and XLV. I have but ſlightly touched on the proper Method for helping *defective Eyes*; I think it convenient to proſecute that matter more fully in this place. Always ſuppoſing what foregoes in the Firſt Part as underſtood.

Firſt therefore for helping the Eyes of *old Men*, as being more frequently and univerſally requiſite than the Relief of purblind Eyes.

In the Firſt Part (*Prop.*XXVIII. *Sec.* 8. and *Prop.*XXXI.) we learn, that a *Convex-Glaſs* is here to be uſed: For theſe ſeeing *diſtant* Objects *diſtinctly*, and *nigh* Objects *confuſedly*, muſt uſe ſuch Glaſſes for reading, &c. as make *nigh* Objects appear *as diſtant*; or, which bring the Rays from each ſingle Point in a *nigh* Object, as if they came from a more *diſtant* Point. Or thus, ſeeing the Cryſtallines of *old Men* are *too flat* for *nigh* Objects, that is, want *Convexity*; we are to help them by adding to them an artificial or adventitious Convexity of a Glaſs. But then our enquiry muſt be, What is a *Proper* Convexity to this or that *particular* Eye? And becauſe reading, or working curious ſmall Works, as being engaged upon *nigh* Objects, are the

the chief Imployments wherein *Spectacles* are requiſite. I ſhall ſuppoſe our Enquiry chiefly deſigned for this purpoſe. And indeed, tho there can hardly be any Rules laid down, *ſtrictly* to determin this matter; for *diſtinct* Sight may conſiſt within a *great Latitude*: Yet if we obſerve the following Directions, we ſhall be apt to err leſs, and to fit our Eyes better with *Spectacles*, than if we obſerved no Rule at all; but choſe at a venture.

Firſt, When we firſt find our ſelves begin to require *Spectacles*, let us make choice of the *flatteſt Convexities*, that will poſſibly help our Eyes. Theſe are uſually called *Young Spectacles*. There are many ways of finding out and trying *ſuch*; but none more ready, obvious, and eaſie, than trying with which one can read a ſmall Print diſtinctly, with the Book *fartheſt* from the Eyes; or try which *Spectacles* burn at the greateſt diſtance; for theſe *Spectacles* are the moſt proper for thoſe Eyes to uſe, and ſhall prejudice the Sight leſs, and preſerve it longeſt of any.

We may note likewiſe, that the diſtance of the Print, or Object from the Eye continuing the *ſame*, a Convex-Glaſs may be ſaid to be *older* or *younger*, according at it is removed *farther from* or *nigher to* the Eye or Object. This is manifeſt from the Doctrine in the Firſt Part, concerning the *Locus Apparens* of an Object through ſuch a Glaſs. To which therefore I refer.

Secondly. If your naked Eyes can read a moderate Print at the full extent of your Arms, or at the diſtance of about two Feet or two and an half; and you deſire a Pair of *Spectacles* to read with, at the uſual Diſtance of reading, *viz.* about a Foot or little more: Procure a Pair of Glaſſes of ſuch a Convexity, that an Object being expoſed before them at the Diſtance of about a Foot, they may have their *Imaginary Focus*, or the *apparent Place* of the Object, diſtant from them about two, or two Feet and an half. All which may be eaſily obtained and effected by the Doctrine in the Firſt Part. Barrow, *Lect. Opt.* 14. *p.*103.

Ee In

In the next place, for relieving the Eyes of the *ſhort-ſighted, pur-blind*, or *Myopes*. We muſt conſider, that theſe, laboring under the contrary Defect with *old Men* (for they ſee *nigh* Objects *diſtinctly*, but *diſtant* Objects *confuſedly*), muſt be relieved with a Remedy of a contrary effect; and therefore they are helped by *Concave-Glaſſes*, which bring the Rays of *diſtant* Objects into the Eye, as if they were *nigh*. And becauſe we may conceive the Cryſtallines of theſe Eyes as too *protuberant* or *convex*, therefore we are to take off from this too great *Convexity*, by adding an adventitious *Concavity*. But then, there is nothing ſo univerſally complained of by thoſe who are thus affected, as the Difficulty they find in fitting proper Glaſſes to their Eyes. For the removal whereof, the following Rules may be obſerved.

Firſt, That for viewing *diſtant* Objects, according to what is noted in the Firſt Part, *Prop.* XLV. If a *ſhort-ſighted* Perſon can read diſtinctly, or ſee Objects at the diſtance of a Foot from his naked Eye; a *Concave Glaſs*, whoſe *Virtual* Focal-Length is a Foot, makes ſuch a Perſon ſee diſtant Objects diſtinctly. And ſo of any otherwiſe diſpoſed Eye. So that knowing the Diſtance at which a pur-blind Perſon reads diſtinctly with *unarmed* Eyes, 'tis eaſie, by the Doctrine in the Firſt Part, to aſſign him a proper Glaſs for his Eye to ſee *diſtant* Objects.

Secondly, For Glaſſes proper for *Myopes* to *read* by, or to ſee Objects at the diſtance of about a Foot and half. Let us ſuppoſe Eyes ſo affected, as not to be able to read, but at the diſtance of Four Inches; and that we deſire Glaſſes for theſe Eyes to read by, at the ordinary diſtance of about a Foot and half: Let us form ſuch *Concave*-Glaſſes, which, being expoſed to an Object at the diſtance of a Foot and half, may have their *Virtual reſpective* Focus at the diſtance of four Inches. And ſo likewiſe for any other Diſtance. All which is eaſily performed by thoſe verſed in the Firſt Part of this Work.

Barrow, Lect. Opt. 14. p. 102.

Thirdly,

Thirdly, We are to note, that *Myops* ſhall require *different* Glaſſes for viewing Objects at *different* Diſtances. But the viſive Faculty not being contained within ſuch ſtrict and determined Limitations; that Glaſs which is uſeful at an Object an hundred Foot diſtant, ſhall ſerve likewiſe at an Object diſtant fifty Foot; but then 'tis not ſo helpful at one diſtant five Foot. But another may be had proper even for this Diſtance, and not ſo uſeful at an Object diſtant an hundred or fifty Foot. All which is manifeſt from the Doctrine in the Firſt Part.

Fourthly, There are ſome Eyes ſo ill conformed, that no Glaſſes whatever will relieve them. Of this I have often heard a very ingenious Man and great Philoſopher Sir *William Petty* often complain in his own particular. But then this proceeds not from a *too little*, or *too great* a Convexity in the Cryſtalline; but from ſome other Indiſpoſition or ill Configuration, not to be relieved by Glaſſes.

Laſtly, Perſons *pur-blind* labour under this great Inconvenience, that the Glaſſes which relieve them in one particular, do hinder their ſtrong Viſion of diſtant Objects in another particular. For as Concave-Glaſſes do order the Rays from any one ſingle Point, properly to be received by the Eye of a *Myops*: So at the ſame time, they *diminiſh* the Appearance of the whole Object. And from hence it is, that tho theſe ſort of Eyes may be well enough relieved for *Reading* and *Writing* at a *convenient* diſtance, and for ſeeing pretty large Objects at the diſtance of 100, 200, or 500 Foot; yet for Objects *much farther*, unleſs they be very *large* indeed, they are not ſo eaſily ſupply'd.

(3.) And here I cannot but take notice of an ingenious intimation of Mr. *Hooks* (to whom the World is certainly much obliged for his curious Contrivances in *Mechanicks*, and his other Philoſophick Indeavours) publiſhed in *Num.* 3. of the *Philoſophical Collections. Lond.* 1681. which he calls *Myopibus Juvamen.* M. Hook's *Contrivance for helping Myopes conſidered.*

Ee 2 'Tis

'Tis briefly this, That ſome ſort of *ſhort-ſighted* Perſons, who cannot be relieved by *Concave* Glaſſes, may perhaps find ſome help in *Convex*-Glaſſes; their Eyes being removed at a convenient diſtance farther from theſe Glaſſes than their *Diſtinct Baſes.* As for reading by theſe Glaſſes; the Book muſt be *inverted*, and then the Image in the *Diſtinct Baſe* ſhall be *erect*, and the Eye ſhall perceive it *erect*. As for Writing, the Difficulty is greater than mentioned by the *Learned Author*: For the *Myops* muſt not only learn to write *inverted*, but alſo *retrograde*, *viz.* from the Right to the Left Hand; and, what is yet more inconvenient, from the bottom towards the top of the Page; which is hardly practicable on account of blotting the wet Writing. As for viewing *diſtant Objects* with theſe Glaſſes; I acknowledg with the ingenious Author, that much of the Diſagreeableneſs of the *inverted Proſpect* is taken off by uſe and cuſtom, as I my ſelf have experienced by my frequent uſe of inverting Teleſcopes. But yet I cannot go ſo far with the Author, as to aſſent to his Deduction from hence; which is, that 'tis only uſe and cuſtom that makes us judge Objects *erect* that are perceived by an *inverted* Image on the Fund of the Eye. For then a Man *ſtanding on his Head*, ſhould judge the Trees and other Objects he ſees *inverted*; which no one in his Senſes will do, but rather judge what is right, *viz.* that he himſelf is *inverted*, whilſt the circumjacent Objects continue *erect*. This will be more evident to us, by conſidering the caſe of an adult Perſon, who has been blind from his Birth, and now ſuddenly reſtored to his Sight: He is not prejudiced by cuſtom, and yet (doubtleſs) would judge as is uſual. But laſtly, an other great Difficulty that will attend the uſe of theſe Spectacles for *Myopes*, is, that they muſt be carried at ſuch a *diſtance* from the Eyes, that it will be very troubleſom to manage them commodiouſly. And if to this again we add the diſtance requiſite for the Object, I queſtion whether ſome Mens Arms will be long enough

to

to manage a Pen for Writing, or turning the Leaves of a Book.

I have been the longer on this Propoſal, becauſe the *Worthy Author* does candidly invite all, to communicate to the Publick, what real Benefit by it, or Objections againſt it, they ſhall find.

(4.) I ſhall conclude this Chapter with the way of Adapting *Teleſcopes* and *Microſcopes* to *defective Eyes*: Which is briefly thus; *Adapting Teleſcopes and Microſcopes to defective Eyes.*

A Teleſcope compoſed of a *Convex* Object-Glaſs and *Concave* Eye-Glaſs, being apply'd to an *old* Eye, the Eye-Glaſs may be a little *farther* removed from the Object-Glaſs than ordinarily: On the contrary, in ſuch a *Teleſcope* for the Eye of a *Myops*, the Eye Glaſs may be removed a little *nigher* to the Object-Glaſs; the reaſon hereof is manifeſt from what has been delivered in the Firſt Part. But then, *how much farther*, or *nigher* they are to be removed, is only to be determined by Experiment, and by every ones fitting the Glaſs to his own Eye.

And ſo likewiſe in Teleſcopes compoſed of a *Convex* Object-Glaſs, and *Convex* Eye-Glaſs: For the Eye of an *old Man*, the Eye-Glaſs may be removed a little *farther* from the Object-Glaſs, or from the *Diſtinct Baſe*. And for the Eye of a *Myops* a little *nigher* to the Object-Glaſs, than for Eyes *naturally* and *orderly* affected.

In like manner for *Microſcopes*; Firſt the ſimple or ſingle Convex for an *old* Eye, is to be removed a little *farther* from the Object; and for a *Myops*, a little *nigher* the Object, than the uſual poſture.

And ſo in *Double Microſcopes*. For an old Eye, the Eye-Glaſs is to be a little *farther* from the Object-Glaſs or *Diſtinct Baſe*; and for a *Myops*, a little *nigher* the Object-Glaſs or *Diſtinct Baſe*. And becauſe in theſe, the *Diſtinct Baſe* is brought *nigher to*, or *farther from* the Eye-Glaſs (without altering the Diſtance

[214]

Diſtance of the Eye-Glaſs and Object-Glaſs), only by removing the whole Microſcope *nigher to* or *farther from* the very Object: This latter Motion effects the ſame as the former; and therefore may be uſed for *old* or *ſhort* Sights inſtead of the former.

[The foregoing reproductions have been made of a size suitable for presentation in this *Journal*. The type-page of the original is, however, five inches wide and seven and one half inches long. The size of the printed sheet in the original is seven inches wide and nine inches long. ED.]

Heterophoria

being the

Doyne Memorial Lecture of the Oxford Ophthalmological Congress 1921

Ernest E. Maddox, M. D., F. R. C. S. Ed.

THE founder, and first "master" of this Congress, Mr. Robert W. Doyne, was an exceptionally ardent benefactor of ophthalmology. To him Oxford practically owed its Eye Infirmary, and the University its diploma in Ophthalmology.

The early meetings of the Congress are alive with memories to many of us, of his genial presence, setting everyone at ease, even including, to our admiration, those unfortunate if honoured patients upon whom members of the Congress were allowed to operate!

On later occasions, the scene changed, and 'pathos' entered. The well-knit frame, inured to manly sports, had been manifestly overworked (for he did the work of two men) and we saw the evening time of life gathering about him all too prematurely; illustrating how

> "Swift to its close ebbs out life's little day,
> Earth's joys grow dim, its glories pass away."

Among many other mementoes, he has left this Congress behind him but not without first committing its welfare to the able hands in which it has continued to prosper.

Introduction

We owe the name, and most of the classification, of heterophoria (which means a 'tendency to differ'), to George Stevens, of New York, whose English ancestors, it is interesting to note, were ancient benefactors of Wadham College, Oxford. For twenty years before his day, hetero-

phoria was studied under other names, such as 'insufficiency' and 'latent deviations,' under the presiding genius of von Graefe, and I notice in the literature that even what we now call hyperphoria was corrected by Mr. W. A. Brailey, more than forty years ago.

Heterophoria is a tendency to imperfection in the oculomotor apparatus, so let us first glance at that apparatus itself. To begin with, there are several things it shares in common with the rest of nature, viz. *on* the surface diversity and beauty, and *under* the surface, unity, balance, habit and rhythm.

The diversity of nature is very evident, but the underlying unity is just as real. Gravitation, for instance, binds the whole universe in one, while radiant energy everywhere fills it with light and warmth. The same laws of motion which guide a schoolboy's marble, are implicitly obeyed by the remotest planet. This principle of diversity in unity is found in every *object* of nature, for the small reflects the great. It is strikingly so in living organisms, and is particularly well seen in the eyes. The cerebral hemispheres make the brain appear double, yet it is really one, and the eyes are windows (also two in one) through which that most deeply hidden of all the systems, the central nervous system, comes to the surface to look out upon the world. It is no wonder, therefore, that Hering long ago described the eyes as a *single organ with two limbs*. This single organ he called the 'Doppelauge' and located it virtually behind the root of the nose. I have ventured to name it the 'Binoculus' as more easily pronounced. Pictures on the maculae are normally referred to the line which connects the Binoculus with the point of intersection of the visual lines. You may ask; "If the eyes are virtually one, why are there two?" The duality of the eyes is necessary for *stereoscopic* vision, to give us two points of view meeting in one; for a wider field; for *safety* in the event of accident or foreign body; for *beauty* (for could you imagine yourselves proposing

to a cyclopean young lady? or a lady with three eyes?), and lastly for silent *eloquence;* for eyes can speak, and, as the poet expressed it, "Soft eyes spake love to eyes which spake again." Together with the lids and eyebrows, the eyes express the passing emotions, as a silent lake reflects the changing sky. Just as the mind is linked with the cerebral cortex, so, it would seem the emotions are linked with the vegetative nervous system, and the eyes are linked with both, for they express both thought and emotion. Their link with the vegetative system is well shewn by the gastric disturbance so invariably met with in acute glaucoma; and conversely, an ice-cream, as Lucien Howe mentions, will often cause a brow-ache. This "reverse action" has a great bearing on heterophoria, for we may sometimes consider it the cause of symptoms when itself is caused by visceral irritation. As regards the muscles, nerves and terminal motor nuclei the eyes are two, but with respect to all higher neurons they are one.

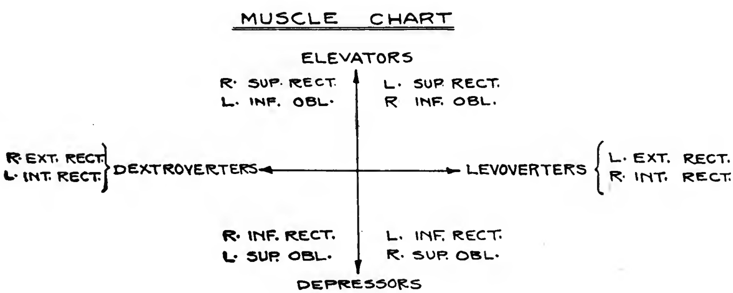
It is a most important clinical distinction that all affections of the final common paths are non-comitant, while all those of higher structures are comitant. Hence in the presence of comitancy we cannot use such expressions as 'weakness of the interni, of the superior recti, the obliques,' or the like. It is not that such conditions are impossible, but if they are present non-comitancy is present. If the internal recti were weak there would be increase of the defect on looking to either side; if the superior recti, there would be hyperphoria on looking to one side, and the opposite hyperphoria on looking to the other side, and similar 'alternating hyperphoria' as we might call it, would be in evidence if the superior or inferior obliques were weak. *Every intraorbital explanation of comitant deviations must be fallacious.*

Divisions of Heterophoria

The first great division of heterophoria, therefore, is

into what I would call 'lower' and 'higher' heterophoria, according as it is non-comitant or comitant. It is clear that we need two different kinds of charts, one for the muscles (Chart I) and one for the reflexes (Chart II), and we need to be somewhat on the alert to know which chart is appropriate to a special case. I believe all reflexes act through the higher neurons. No single muscle is affected by a reflex.

CHART I



Lower heterophoria—that is, heterophoria due to one or more affected muscles—is, I think, very often over-looked, because we are so much in the habit of confining our measurements to the primary position where it may not show itself. The four diagonal areas of the motor field are easily investigated by the disc of rods, the patient's head being placed in the required obliquity before a large tangent scale on the wall. If the disc is not held quite in a vertical plane, however, the red streak appears curved, which may vitiate the test. To guard against this I employ a disc swung as from a gallows, which hangs truly without being able to rotate about a vertical axis. I find this extremely suitable for measuring the torsion of the false image, and I have asked the makers of my tangent scale to let the scale be fixed to the wall by a single screw at its centre of gravity, to allow of its rotation by an assistant,

CHART II

Oculomotor Reflexes

(*Suggested Classification*)

KINGDOM 1: OR HOME OFFICE

(To Create the Binoculus)

HORIZONTAL	1	Convergence (Eyes approximate).
	2	Divergence (Eyes separate).
VERTICAL	3	Right Hypervergence (R. rises & L. falls).
	4	Left Hypervergence (L. rises & R. falls).
TORSIONAL	5	Incyclovergence (Both twist in).
	6	Excyclovergence (Both twist out).

a Function = Fusion
b Prevent diplopia
c Unify the eyes
d Take account of third dimension of space and give consciousness of distance of objects
e Involuntary
f Motions contrary
g Stimulus = Desire for single vision
h More linked with the vegetative system
i Meissner's torsion

KINGDOM 2: OR FOREIGN OFFICE

(To direct the Binoculus)

HORIZONTAL	7	Dextroversion (Both turn to left).
	8	Levoversion (Both turn to left).
VERTICAL	9	Surversion (Both rise).
	10	Deversion (Both sink).
TORSIONAL	11	Dextrocycloversion (Both twist to right).
	12	Levocycloversion (Both twist to left).

a Function = Fixation
b Powerless with diplopia
c Direct the gaze
d Take account of first and second dimensions of space and give consciousness of direction and attitude of objects
e Mostly voluntary
f Motions parallel
g Stimulus = Desire for macular perception
h Linked with labyrinths, and somatic equilibrating system
i False torsion

until it is parallel with the streak of light. A weak vertical prism before the other eye, or clipped on to the disc of rods, makes the test easier. I sometimes use a rotating wand attached to the wall, or to an old Bjerrum screen, by a nail through its centre. The diagnosis of paretic muscles is, of course, made on the same principles as for frank paralysis. I still think that, for the vertically acting muscles, the best method is that outlined in my book on the *Ocular Muscles*, namely: to make the diagnosis from the vertical separation only, and then confirm it by the torsion, leaving the horizontal element out of account.

Let us now consider *higher heterophoria*. I would like to draw your attention to the twelve beautiful reflexes of which I believe six preserve the eyes in one, while the other six make them dance hither and thither like a pair of merry children hand in hand. Some of them are familiar to you, others probably not. They are in six reciprocal pairs, on the "give and take" principle, and they no doubt have the "reciprocal innervation" discovered by Sherrington.

Hering took account of only five motions in framing his theory, and modern text-books of physiology enumerate no more, but in ophthalmology, others have gradually made themselves evident during the last thirty years, and I think now all these twelve are definitely proved, except the second, in favour of which two reasons might be given, and two against. I have tried to classify them into natural orders, as shewn in this chart.

Another list, I ought to say, has been made by Professor Savage of Nashville, a list of ten, but differing from mine as being on the lines of lower heterophoria instead of higher; that is to say they are in terms of the muscles. The most interesting division I have found of the twelve reflexes is into two kingdoms or groups, one of which might be called the 'Home Office,' since its function is to settle the domestic differences of the eyes; and the other the 'Foreign Office' since all its interests are abroad. In the former the motions

are all mutual, *i. e.* towards or away from each other; in the latter, all parallel. These two groups never usurp each other's functions, and yet work in perfect harmony. They are like a white man and a black man working harmoniously at two ends of one saw, and yet the white man always white, and the black always black. Indeed, what Hering found true of convergence and the lateral movements of the eye may be extended I think to the whole of each kingdom.

The third dimension in space is the only one that interests the 'Home Office,' while the 'Foreign Office' is exclusively concerned with the first and second dimensions. The 'Home Office' effects fusion, the correction of diplopia, and the formation and preservation of the binoculus. It cannot direct the binoculus in the smallest degree. The 'Foreign Office' alone can do that and is concerned with fixation, orientation, equilibration and version. The 'Home Office' acts under the stimuli of threatening diplopia of six different kinds. The 'Foreign Office' is powerless to correct the smallest diplopia of any kind and acts under the stimuli of volition from above, combined with a subordinate fixation reflex from below. Miners nystagmus is, I believe, largely due to a conflict between volition and the fixation reflex, since the glitter on the coal solicits the latter while a blow is being voluntarily aimed at a non-glittering spot. This is only by the way. I think you will find the 'Home Office' is more in touch with the vegetative nervous system, and the 'Foreign Office' with the somatic nervous system and the labyrinths. This is a very interesting distinction if true, explaining why worms, indigestion, and teething, cause not parallel deviations, but squints, and I have definitely proved my own slight esophoria to be increased by gastric irritation.

These two kingdoms may therefore be looked upon as two compound reflexes, playing a duet, as it were, upon the terminal nuclei of the twelve ocular muscles. They never strike single notes, but always *chords*. That is to say they

never actuate single or even pairs of muscles. Now, I have no doubt, since the same chords have to be struck again and again, that linkages are formed between even the oculomotor nuclei of the 3rd, 4th, and 6th nerves, to mechanicalise the work, just as linkages are opened up to the spinal cord for the fingers. For indeed the lower motor neurons of the ocular muscles are in series with those in the anterior horns of the spinal cord, just as the ciliary ganglion is in series with the prevertebral ganglia.

The Reflexes

The first reflex, (to take them now in detail) is an old friend, viz: that for *convergence*, the slackness of which causes exophoria, and its excess esophoria. (I prefer the English pronunciation to the Greek (esophoria) as distinguishing the sound better from exophoria.) Fig. 1 shews how the visual lines are approximated towards the point of fixation by accommodative convergence, aided by postural habit. This is the coarse adjustment. The small bracket represents the fusion reflex which effects the fine adjustment. It not only makes the lines meet, but fastens them together.

You may wonder what is meant by the larger bracket. It represents a fusion-reflex augmented by voluntary effort. The arrow above it represents directed energy from above, perhaps from the angular gyrus, which Gordon Holmes has shewn to be connected with visual attention.

However great the postural defect may be, if compensatory hypertrophy has made the fusion reflex large enough to easily overcome it, the heterophoria may be regarded rather as a harmless anomaly than as a pathological symptom. But the moment the work to be done is almost as great as the workman, the latter begins to labour, and trouble begins. The fusion reflex then borrows energy from the centrons of neighbouring reflexes, and from the cerebral cortex, in the form of the 'forced attention' referred to.

Now a reflex is a machine, that is to say, a labour saving

device, far more economical than voluntary effort. Sherrington has shewn how especially untiring are the postural reflexes connected with the gravity muscles and no doubt

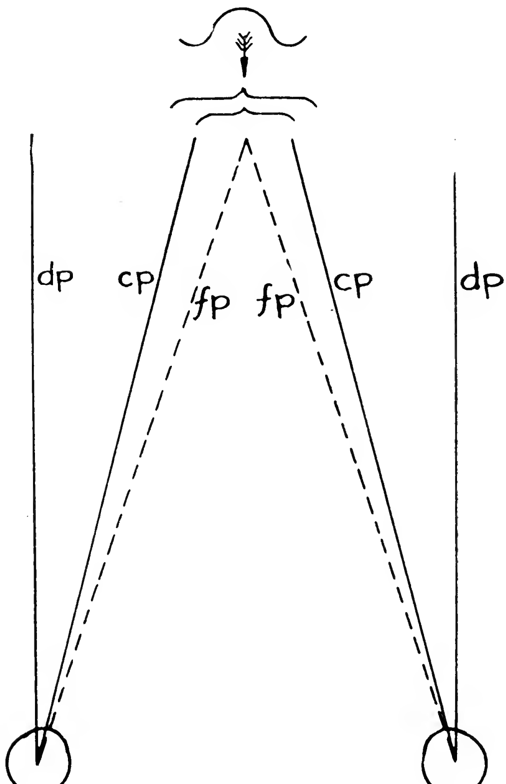


Fig. 1. The coarse and fine adjustments of convergence. Distance posture *d p*. Convergence posture *c p*. Fusion posture *f p*.

something similar could be said about those of the eyes, especially of the Home Office. We have lately heard from him that the katabolic waste of voluntary motion is half a million times greater than of these postural reflexes.

Whether the figure is correct or not it at least makes us think. The cortex is the last part of the brain to mature, and the first to fail, and its exercise is the most tiring. The angular gyrus lies pretty far back, and the cerebellum has so much to do with these reflexes that the frequency of occipital headache in uncompensated heterophoria is not surprising, especially if the ablo-ascoid muscles are also wearied.

Since convergence is the strongest and most trainable of all the reflexes, its slackness (called exophoria) rarely needs treatment by prisms. Its link with accommodation enables us to influence it by spherical lenses, a treatment which next to constitutional measures, is the best. The correction of astigmatism also, and of hyperphoria, helps to preserve the converging reflex from being robbed of its energy. For esophoria we use lenses which *fully* correct hypermetropia. For exophoria, generally those which *partially* correct it; but not always, for in neurasthenia a full correction may be best. "Exophoria with hypermetropia" has always been a great puzzle, but I think it due to a limited amount of nervous energy, of which so large a share is needed for accommodation as to leave too little for convergence. For many years I have treated exophoria in healthy young people by concave lenses, so as to invoke even superphysiological exercise of accommodation, and thus harness their abundant accommodative energy to the task of sensitising the converging reflex.

The *diverging* reflex (No. 2) is the only one I have not been able to positively prove. Exophoria from "divergence excess" is still only a theoretical conception. It is moreover almost impossible to distinguish between inhibitory neurons, acting on convergence, and a positive reflex acting on the external recti as its effectors. However, the analogy of the other reflexes disposes me to believe in the latter. Indeed, I suggested, thirty-five years ago, in the *Journal of Anatomy and Physiology* that the external recti were in-

nervated by the sympathetic in antagonism to convergence, just as the dilator pupillae antagonises the sphincter. In any case, there must be some mechanism, the proper stimulus of which is threatened homonymous diplopia, and which when damaged by haemorrhage causes sudden convergent strabismus. So I have ventured to include it in my chart, with all deference to Sir George Berry's able arguments otherwise. Convergence may possibly be governed by vagotonic fibres if my thought of sympatheticotonic control of divergence is correct.

I think all the reflexes of Kingdom I are (to borrow Sherrington's term) *postural*, and those of Kingdom II *phasic*. Certainly the vergences are less powerful than the versions. I have sometimes thought they are slower. The modern theory that the sarcoplasm is controlled by the sympathetic, and the sarcostyles by the voluntary motor nervous system may if true have a bearing on the two main groups of oculomotor reflexes.

Nos. 3 and 4 are remarkable reflexes, which I believe to be of a *see-saw* nature. I have chosen the name hypervergence, not because it is the best, but to be in a series with hyperphoria. If a prism is held erect before one eye to test the prism vergence, that one eye rises to overcome it, I believe, by one of these see-saw reflexes, in combination with the surverting reflex No. 9 which simultaneously raises both eyes equally, to preserve the naked eye from displacement. This arrangement looks so needless and complicated and it would be so much simpler for each eye to have the power of monocular adjustment (Prism-duction), that for many years I only mentioned these see-saw reflexes as probable in spite of the skew deviation of the eyes sometimes noticed when the middle peduncle of the cerebellum is damaged, until one day I had a remarkable patient who later went by the name of 'Old See-Saw,' for one eye rose as the other fell, in large regular, slow sequence. This settled my last doubt. A little consideration will shew that such an arrangement must

be, if each of the two Kingdoms is to be true to itself. This figure (Fig. 2) shews what would happen were right hypervergence to take place by itself, while Fig. 3 illustrates the sim-

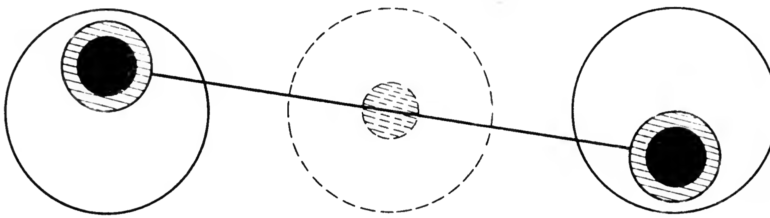


Fig. 2. To illustrate the "see-saw" motion of right hypervergence. (Note immobility of Binoculus)

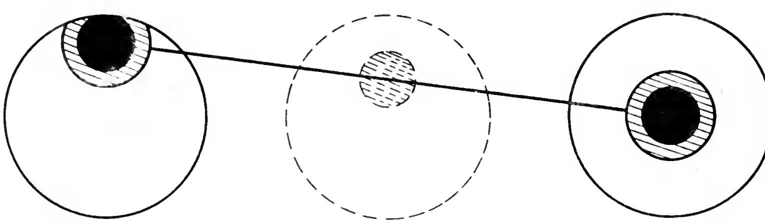


Fig. 3. Combined right hypervergence and (binocular) surversion. (Note rise of Binoculus)

ultaneous surversion of both eyes, by reflex 9. In the first figure the 'Binoculus' remains stationary; in the second it is raised half as much as the right eye, so that objects appear displaced upwards, through half the deviating angle of the prism, and this I have proved to be the case. It will be noticed that the see-saw motion alone leaves the Binoculus unmoved. It is most important that the mind should be sensible of every movement of the Binoculus, and since Kingdom I is incapable of imparting such sensation, it defers all movement of the Binoculus to Kingdom II. Herein we detect the reason for an arrangement which appears needlessly complicated. It enables each kind of reflex to mind its own

business, and to supply correct information to headquarters.

The normal function of the see-saw reflexes is to preserve the fixation lines in the visual plane. When we wear cylinders with oblique non-parallel axes, the see-saws are in constant alternating exercise as we look from side to side, since the prismatic effect of the lenses is such as to cause alternating hyperphoria. This is one of the chief reasons why oblique cylinders are so ill tolerated.

Since the hyperverging reflexes are of small amplitude, hyperphorics are nearly always grateful for correction by prisms. They are the least trainable of all the reflexes.

The *cycloverging* reflexes (5 and 6) cause the vertical axes of the eyeballs to mutually incline towards or away from each other. They act rather more on the obliques than on the recti, but so as to be thoroughly comitant in their effect, which could not of course be possible were they to act on the obliques only. They not only correct cyclophoria but have I believe an extremely interesting part to play in ordinary vision, for, if I am right, they enable the retinal images of sloping lines in the median plane to fall upon corresponding meridians. If I hold this penholder in the median plane, but with its upper end further from me than the lower, reflex 6 (excyclovergence) comes into play, otherwise I should see the pen double, with images crossing, while if the slope of the pen be reversed, so as to bring its upper end nearer to me, reflex 5 (incyclovergence) is active.

It is well known that when two arrows are depicted diverging above on a stereoscopic card they appear, when fused, to shoot away from the observer, but when diverging below to shoot towards him.

Cyclophoria in distant vision is easily measured by the glass rods as already described, or by cyclophorometers, and the result is sometimes valuable in helping us to decide which muscle to select for an operation. In my own eyes there is slight excyclophoria when fatigued, as by a long walk. In the year 1890 George Savage discovered the prev-

alence of excyclophoria in near vision while experimenting with my double prism, and seven years later George Stevens published his first paper on declinations. More than sixty years ago, however, a torsion of the eyes in near vision was greatly studied by Meissner (1858), Volkmann, Helmholtz, and others, and later by Le Conte.

I will now invite you to make an experiment yourselves. Draw an upright arrow or line on the back of your programmes, and hold it closer to your eyes than the near point of convergence so that you see two arrows. In all probability they diverge above, shewing excyclotropia, since the images are crossed. If now you raise the paper so as to look under your eyebrows the mutual slant increases, but if you lower it so as to look down as far as possible, the arrows become parallel. This proves that in near vision there is a physiological excyclophoria, except on looking down, and that it gradually increases as the eyes are raised, and also, it may be added, as the object of fixation is brought nearer. We learn from this, what Helmholtz pointed out from Meissner's test, that in near vision the primary position of the eyes is one in which the visual plane is depressed, and indeed, we naturally cast our eyes downwards for near objects to let the hands and eyes work together.

If now you look at the same arrow with the eyes turned up to the right, you may notice one arrow rise higher than the other, while with the eyes turned up and to the left, the other arrow may rise. In my own case the rising arrow indicates an alternating hyperphoria which points to comparative inaction of the superior recti as a partial cause of the cyclophoria, so that it may have both a "higher" and "lower" element.

Before leaving the subject of cyclophoria I might mention that in Professor Savage's list, the place of these cycloverging reflexes is taken by what he calls "harmonious symmetrical action of the obliques"; but I would suggest that harmonious action of the obliques is impossible. They would cause

CHART III
Conjugate Oculomotor Nomenclature

KINGDOM I. OR HOME OFFICE			
	MOTIONS.	PHORIAS.	TROPIAS.
1	Convergence	Esophoria	Esotropia
2	Divergence	Exophoria	Exotropia
3	R. Hypervergence	R. Hyperphoria	R. Hypertropia
4	L. Hypervergence	L. Hyperphoria	L. Hypertropia
5	Incyclovergence	Incyclophoria	Incyclotropia
6	Excyclovergence	Excyclophoria	Excyclotropia
KINGDOM II. OR FOREIGN OFFICE			
	MOTIONS.	PHORIAS.	TROPIAS.
7	Dextroversion	Dextrophoria	Dextrotropia
8	Levoversion	Levophoria	Levotropia
9	Surversion	Anaphoria	Anatropia
10	Deversion	Kataphoria	Katatropia
11	Dextrocycloversion	Dextrocyclophoria	Dextrocyclotropia
12	Levocycloversion	Levocyclophoria	Levocyclotropia

Vergences are contrary motions of the eyes (mostly involuntary).

Versions are parallel motions of the eyes (mostly voluntary).

Prism-vergences are changes effected in the mutual posture of the eyes by prisms which are "overcome."

Ductions are drawings of a single eye in any direction by its muscles.

Torsion means twisting of an eye about its own fixation line = wheel-motion.

Cyclovergence means mutual contrary wheel-motion of the two eyes; **cyclotropia** the result; and **cyclophoria** the tendency thereto.

Declination means angular departure of the vertical axis of one eye from parallelism with the median plane of the head.

Phorias are "tendencies" checked in Kingdom I. by the fusion reflex; and in Kingdom II. by the desire to keep the head straight.

Tropias are "turnings," causing in Kingdom I. squint; and in Kingdom II. inclinations of the head.

The prefixes **sur** and **de** are contractions for "sursum" and "deorsum" (compare surmount, deject, etc.).

"alternating hyperphoria," for on looking to the right or left the elevating power of the ipsolateral obliques lessens, and that of the contralateral obliques increases. At the same time it is pleasant to own that his theory aimed at the true thing; it only needs translating from lower or incomitant, into higher or comitant heterophoria to be correct.

The first four reflexes of Kingdom II are too well-known to be dilated upon. They were named "versions" by Duane. I have ventured to shorten the awkward prefixes 'sursum' and 'deorsum' into 'sur' and 'de.' These parallel motions are both voluntary and reflex. In their defects no diplopia can be elicited by the glass rod. There may be a limitation of version, *i. e.* of parallel movements of the eyes, in one direction, or there may be merely a preponderance of one reflex over its antagonist. I regard it as a phoria if there is no vicarious inclination of the head. If the head be turned to save the weak verting reflex it is, I suggest, no longer a case of phoria but of tropia. Stevens made a great study of anaphoria and kataphoria (but without making this distinction), and more recently Valk has written, well and ably, on dextrophoria and levophoria, as studied by Stevens' troptometer. As so many become confused about nomenclature, I have drawn up chart No. III.

The *cycloverting* reflexes (11 & 12) incline the vertical axes of the eyeballs parallelwise to right and left. They are, I am satisfied, well proved, and even their amplitude can be, to some extent, measured. They enable us to judge of the erectness of objects. When we look at a picture, for instance, to see if it is straight on the wall, we instinctively incline our heads slightly to one side and the other to put these reflexes on the 'qui vive.'

It is only in this indirect way that they might be called voluntary. They are also involuntary steadiers of the eyes in its other parallel movements, but they do not, as some might suppose, either cause or nullify "false torsion" for that

is already perfectly accounted for, as a simple mathematical necessity, by composition of the vertical and horizontal parallel movements of the eyes.*

Lucien Howe, author of the most complete textbook on the *Ocular Muscles*, has suggested a number of other innervations for the oblique movements of the eyes, but as I cannot discover these, I have not charted them.

Tests for Heterophoria

Let us now consider a few *tests* for heterophoria. That which first of all led me to pay attention to muscle balance, was the discovery, while experimenting with two pin holes in a piece of paper, that I had a slight esophoria for distance. To investigate this more fully, and at the same time find out how one eye would behave if placed in the dark, I constructed this dark box nearly forty years ago, and it was kindly shewn by Mr. Nettleship to the Ophthalmological Society. Its aim was to utilize the blind spot to record the movements of a darkened eye. I found by its use that I had an exophoria of about one metre angle in near vision and to my surprise a great many others had similar deviations of varying degree, so much so, that for a time I called it "physiological exophoria," a name which I have now abandoned since it might make the numerous exceptions which occur, especially in young people, to be thought unphysiological. Von Graefe's test for near vision, till then universally employed, consisted of a dot with a line through it,

*Professor Savage has published a theory that in the oblique movements of the eyes, the vertical axes of the eye-balls are preserved in parallelism with the median plane by 'harmonious non-symmetrical action' of the obliques, that is to say, the right superior oblique working with the left inferior, and the left superior with the right inferior. I regret my inability to endorse the views of so earnest a worker, for to begin with, the vertical axes of the eye-balls do become inclined to the median plane in the oblique movement of the eyes as a necessary consequence of Lishing's law, just as the horizontal axes become inclined to the horizontal plane in the opposite sense: and secondly any such combined action of the pairs of obliques named would result in a vertical squint. For example, if the right superior oblique were to act with the left inferior oblique, the right eye would sink and the left rise.

reduplicated by a prism, base down before one eye. It did not seem to occur to von Graefe that the overlapping of the portions of the line would suffice to maintain fusion, so that his test only revealed deviations in extreme cases, and led to the belief that the normal relation between convergence and accommodation was a fixed one. I must resist the temptation to describe a number of other experiments with this box from which indeed I learned most of what little I know about oculomotor physiology. A better way of using it is to disregard the blind spot and make the two points of light appear one over the other when the deviation can be read off direct. Its findings were confirmed by two other tests; which occurred to me all the same time, namely: the double-prism and the arrow tangent-scale, both of which were much used for some years until the first begat the rod-test, and the second the wing-test. Perhaps the prettiest appliance I have made is the twin-test, consisting of two celluloid sheets of complementary colours in apposition, and so pricked through that designs appear which can be brought to coincide. My near vision phorometer also in complementary colours is quite good if well made, but I have not brought it today, for neither method secures the accommodation quite so well as the wing-test. I find in practice that, on the principle of the survival of the fittest, I have gradually dropped all other tests except the rods for distance, and the wing for near, supplemented by the redress and the parallax tests (the latter so ably advocated by Duane), and my prism-verger occasionally. I think no refraction is complete without measuring both the distant and the near posture. The rod-test you probably know already; I like it made with very thin rods, and not too small in area. It is best used in a room dark enough to avoid adventitious reflections, and yet with enough light to secure accommodation. I have in my own eyes esophoria of 1°, but if one eye be screened I have a ½° only. I have found many both in far and near vision have about ½° less esophoria, or ½° more

exophoria, on screening. This is due to slackening of the converging reflex when one eye is completely covered. In the wing-test both eyes receive a natural stimulus to accommodation. I have crowded the wings close to the eyes for horizontal measurements to avoid exciting the ciliary muscle, for objects which are hopelessly near do not tempt accommodation. It is important to make sure that the apparatus is correctly made, so that the object intended for each eye is entirely hidden from the other. I have provided the rotating wing-test with a means of measuring cyclophoria, both by vertical and horizontal lines, using the distant pillar for the first, and the wings set nearer and cross-wise for the second. You will generally find a difference between the two measurements, due at any rate in part to the curious fact investigated by Helmholtz and others, though denied by Savage, Stevens, and Le Conte, that the physiological dividing line between the two lateral halves of the retina is not perpendicular, but slants down and in. I have investigated the point and I find the "Helmholtz retina" exists in most eyes, but not in all. The 'wing-test' is of great service in the correction of presbyopia. If the arrow trespass ever so little on the esophoric side, we may safely increase our correction, while an unusual degree of exophoria will make us careful to keep it as weak as we can without loss, though of course other considerations come in as well. The most important minute of a refractive consultation is that in which we deliberate what reading lenses to order.

The 'wing-test' can also save us sometimes from over-correction of hyperphoria. We may, for example, find 2° for distance and about 1° in near vision. For hospital use, my rotating pattern is rather fragile, and I have for many months tried to puzzle out an instrument free from all movements, and therefore stronger. I have at last succeeded. One fixed chart now measures the horizontal vertical, and torsional elements all "in one go." After the horizontal balance has been measured, the arrow should be set at an angle that

makes it appear horizontal to the patient. Then we can read off the hyperphoria and the cyclophoria.

Treatment of Heterophoria

The treatment of heterophoria becomes a simple matter as soon as we thoroughly understand the nature of a case. Each needs taking on its own merits. I need only touch on some elementary principles.

1 Discover the cause and remove it if possible.

2 Correct any error of refraction with perhaps a little decentering of the lenses in the direction of relief. At the same time treat the constitution with any necessary advice as to regimen and the use of the eyes. If symptoms entirely disappear, no more need be done, even if the heterophoria remain. It will almost certainly be less in time, since every organism tends to "come to itself" when freed from adverse influences.

3 If lateral deviations are complicated by hyperphoria correct the vertical deviation first and the lateral will very likely correct itself.

4 If after the above treatment some symptoms still continue, train the weak reflex or the weak muscle as the case may be. Training is chiefly indicated in young people. It is only suitable for older ones when they are possessed of sufficient vigour. In neurotic or neurasthenic cases it should not be commenced until the nervous system, both ocular and bodily, has been strengthened, and should be commenced during a holiday or bracing change. Undue recession of the convergence near point (or sub-convergence as I like to call it) can be trained by drawing an arrow on a piece of paper and approaching it to the eyes again and again while endeavouring to keep it single. Reber's lateral version exercises may help somewhat, in the same way that rowing helps writers' cramp, by bringing fresh blood to the structures concerned without actual exercise of the weakened neurons. Prism exercises come next. I often give young people a

second pair of spectacles resembling those they wear, but with adverse prisms incorporated, and bid them wear these training spectacles at certain favourable hours of the day. As an alternative to this, one or two "grab" prisms can be slipped on to the spectacles in ordinary wear. Whenever the prisms are more easily overcome in near than in distant vision they can begin by looking at a point on the wall close up to it and then receding backwards to the other end of the room repeating this again and again early in the morning or after breakfast or rather before the eyes are tired. When glasses are not worn I order prisms set in circular rims, so that as the reflex is strengthened, the base-apex lines can be made to lie at greater and greater angles to each other by rotating the prisms in the frame. Lastly, the most powerful training of all is obtained by the simultaneous rotation of two prisms as in my prism-verger, the object being a disc of ivory or white paper in the centre of a Bjerrum screen. My verging prisms (*i.e.*, rotating towards or away from each other), can be conveniently mounted also either in a phorometer or in a stereoscope. Training in the consulting room however is only practicable for those surgeons who are blest with sufficient leisure.

5 Operation. This generally is the last resort after we have helped nature to do her best. It is invaluable in some cases and especially when we can convert a non-comitant deviation into a comitant one (Duane). Hence before operating, the whole field should be measured to find a weak muscle, the operation should be planned so as to simultaneously correct any cyclophoria, and in lateral deviations any hyperphoria. Lastly, the strength of the opposing reflex should be measured by prism-vergence, especially for a tenotomy. I say the opposing *reflex* because it is not enough for the opposing *muscle* to be strong. (For example, however strong the internal rectus may be, we shall obtain no effect from tenotomy of the external in the primary position if the converging reflex is inactive. The internal rectus may be

strong for phasic motions, and yet the posture be weak.) Exercise of the convergence, however, may often be trusted to bring about a sufficient augmentation of the reflex to make tenotomy advantageous. I have had excellent results from graduated tenotomy of an inferior rectus for old standing paralysis of the opposite superior oblique (restoring the head, for example, in the case of one medical friend to the erect position, after being tilted for years toward one shoulder). Even cyclophoria is sometimes worth operating for. I have recently seen a patient on whom I operated for this more than twelve years ago. Previously to the operation he had headache without intermission for seven years dating from typhoid, and he has had no headache since. But these operations are extremely tricky, and in higher heterophoria it is rather a responsibility to convert a comitant defect into a non-comitant one by operation. Here again, however, nature comes to the rescue, and gradually restores more or less comitancy if a muscle is only tenderly dealt with by operation, on the principle of "reversion to organism" as we might call it.

The most successful surgeon is the one who respects nature most. You may perhaps wonder that I have said nothing about the evolution of the oculo-motor apparatus, but, gentlemen, when I look at your intelligent faces, and the soul in your eyes, I cannot bring myself to believe that you are descended from maggots and spiders and pigs. The whole voice of nature, as I hear it, is against that fantastic theory. Nature is conservative and not progressive. She reverts to type as soon as the reason for departure from it disappears. When I see a piano, I do not at once jump to the conclusion that because the keys are in progressive series, therefore they must have evolved out of one another!

I thank you, gentlemen, for your kind attention, and I have now the pleasure of laying this imperfect lecture as a little memorial wreath upon the tomb of our friend and benefactor, Robert Walter Doyne.

Glenartney, Poole Road,
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Editorials

Uniocular and Binocular Fusion Comparisons

IT is possible that the explanation of fusion in binocular vision is to be found in a common cerebral center for each pair of corresponding points, and this was the view held by many of the older physiologists. Newton, Wollaston, Rohault, J. Müller and others regarded the fact that a sensation initiated from corresponding retinal points is referred commonly without ambiguity to a single locus in visual space as evidence of the community of the nerve apparatus belonging to the paired retinal points. Their visual image appears *single*. Wollaston made the assumptions that the twin points were attached to one and the same nerve-fibre and that these bifurcated at the chiasma. That the points were served by twin-fibres from the same ganglion-cell of the cerebral substance was the opinion of Rohault and Müller. Later, Aubert took the visual singleness and the spatial fusion of right and left impressions to give a single perception as an evidence of confluence of the nerve-processes from the right and left retinae to a single common center or point of the sensorium. And still later, the discovery that the fibre-tracts from corresponding halves of the retinae both go to the occipital region of one and the same hemisphere has been inferred (*e.g.* Ramon-y-Cajal, Schäfer) to indicate a spatially conjoint visual sensorium common to both retinae. But, as has often been remarked by others, the inferences or deductions obtained from anatomical considerations only may be equivocal and very remote in their bearing.

There are, therefore, many facts which are inconsistent with the foregoing opinions and views, especially those presented in the researches of Sherrington, Macdougall and

Hartridge. It is with the view to presenting evidence as against the commonly accepted notion of a common cerebral center for both corresponding points that we furnish in the paragraphs which follow a résumé of some of the work of Sherrington.

Some years ago Dr. Charles S. Sherrington delivered the Silliman Memorial lectures at Yale University and took as his subject, *The Integrative Action of the Nervous System.* The last lecture dealt with Sensual Fusion and, in order to compare with the simultaneous coördination of the nervous factors in a motor reflex, the synthesis of the various elements whose combination underlies a simple sense-perception, he took the visual act and in particular a comparison of various judgments as formed by each eye individually on the one hand and as formed by binocular fusion on the other hand. The experiments which Sherrington performed and published (*British Journal of Psychology*, Vol. 1, 114, 1904) lead to some important conclusions with reference to Talbot's law and the binocular retina, uniocular and binocular brightness and contrast, and visual fusion and neural union.

In order to carry out his researches, Sherrington devised his rotating lantern, with cylindrical screen and suitably arranged holes together with a screen so set as to keep all view of the right-hand holes from the left eye, and *vice versa* (vide: *The Integrative Action of the Nervous System*, pages 357-362). The apparatus was so arranged that a definite timing of openings for either eye was possible. Furthermore, it could be arranged that the uppermost circular hole was open when the lower ones were closed, or was shut when the lower was closed, or was open to any desired degree. The apparatus, therefore, made it possible to have a flicker system for each eye, the system for one eye being spatially higher than for the other in order to make it possible that one set of apparatus only should be involved, hence obviating difficulties of adjusting two separate systems in a definite time relationship of right and left eye flicker respectively.

By means of weak prisms with base-apex lines vertical the images of the right-hand and left-hand holes could be brought on the same horizontal level. The four images formed could then be fused to two by convergence, and by means of horizontal threads halving each of the middle holes and similar but vertical threads halving the other two holes, binocular vision could be certified to the observer. This arrangement, therefore, permitted: (a) Images accurately similar were received by retinal areas accurately visually conjugate; (b) the areas were not only of so-called "geometrical identity" but were in full binocular coöperation; (c) extinction and illumination of the images occurred *pari passu* in the two eyes—with like speed and in like direction; (d) synchronism or any time-sequence desired could be secured; (e) each disc-shaped image had a diameter of 570μ so that when foveal vision was directed upon it, the image occupied a particularly rod-free area containing nearly three-thousand cones; (f) the direction of translation being the same for all shutters, the bright images on the two retinae commenced on "identical points" of the two retinae and finally ended along such "identical points," or if the shutters were set for accurately alternate right and left images, the screening off in one eye began at a spot and time identical with those at which the turning on of the image commenced in the other eye; (g) that the retinal points were identical was attested by the facts that the paired physical images were seen single and the maximum disparation of the edges of the rotatory shutters was about 7μ on the retina and (h) difficulties due to change in pupil-width were excluded by artificial pupils. By virtue of these arrangements identical retinal points were assured and the foveal gaze could be turned from one to the other of the haploscopic images by less than three degrees of movement of the eyeballs, thereby making a comparison easy and sure.

In a set of experiments conducted with symmetrical flicker it was found that similar phases of flickering illumina-

tion, if timed to fall coincidently on conjugate retinal areas, do very slightly re-inforce each other in sensation and if timed exactly alternately do very slightly mutually reduce each other. The broad outcome of these experiments is that bright phases at one eye do not efface dark phases at the corresponding spot of the other eye, and hence there is hardly any trace of interference. So far as sensual effect goes, therefore, the light phases of one eye do not practically interfere with or combine with the coincident dark phases at the other, nor do they in the alternate right and left arrangement add themselves as a series of additional stimuli to the like series of stimuli applied at the other eye.

Experiments in which asymmetrical flicker existed suggested that the addition of the steady brightness at one eye to the dark phase of the intermittent image at the corresponding point lightened the latter and its addition to the phase of equal brightness with it left that practically unaltered. And the supposition of interference with or combination with the individual phases of reaction to the intermittent image at the corresponding area is denied by the observations with symmetrical flicker.

And again, Talbot's law holds for the single eye throughout a wide range of ordinary intensities with intermittent light, and also for the two eyes if used together in arrangements equivalent to the simultaneous right-left method for symmetrical flicker. The question arises: How nearly does it amount to the same thing as far as visual brightness is concerned, whether the next incidence be upon the same retinal point or upon the twin (corresponding) point in the other retina? By the "alternate right-left arrangement" and speeds of the lantern too high to allow flickering, it was found that not only does Talbot's law not hold for the double retina considered as functionally single, but there is no trace of observance of the law. Hence the two corresponding points, in this respect at least, do not integrate to a single retinal surface. And further, it was found that, with all

four lantern images of equal luminosity using intermission frequencies too rapid to permit of flicker, the brightness of the binocular combinations of any two did not distinctly exceed that of the uniocular. Hence, the general conclusion:—"A binocular brightness compared with its monocular components is of value not greater than the greater of these, nor less than the lesser of them, and that its value is about the arithmetical mean of the two uniocular components as expressed by the measures of the physical stimuli yielding them." Therefore, a binocular combination of a less bright image with the brighter one gives a visual image of less brightness than the latter: but the application of the less bright physical image to the *same* uniocular area as the more bright image gives a visual result of brightness greater than either. The first statement contained in the foregoing sentence is also illustrated by Fechner's paradoxical experiment. In this, one eye is directed to an illuminated surface such as a sheet of white paper, while the other eye is kept closed. If a sheet of smoked glass is inserted before the closed eye and the latter in turn is suddenly opened, the field of vision will appear distinctly less bright. In this instance, therefore, the additional stimulation of the second eye due to the light which has passed through the smoked glass adds nothing to the sum of the brightness stimulation, but rather detracts from it. Also, a steady image presented on an area of one retina damps the flicker of a flickering image simultaneously presented at the corresponding area of the other. A steady image physically superposed on the same retinal area as a flickering one also reduces this flicker in accordance with Weber's law. But the modes of interference and the number of phases per second necessary for flickering are entirely different in the two cases, showing that the double retina cannot be considered as functionally equivalent to a single retina.

The facts relative to "predominance of contours" are among the most significant as showing the difference between

binocular and uniocular fusing of visual reactance. An experiment from Sherrington of this character illustrates the point: A steady non-flickering disc-shaped image L is presented to the left eye and across the disc is a narrow dark line. An image R of similar size and shape but without the dark line is presented to the corresponding area of the right eye. If the luminosity of L is slowly diminished there is finally reached a luminosity at which its cross-line, though visible when L alone is observed (*i.e.* right eye closed) is lost or uncertain in the binocular image R-L. This reduction of the luminosity of L much exceeds the reduction at which its cross-line is lost when the image R is simultaneously thrown on the same area of the same retina (*i.e.* left retina). Thus, in one experiment the diminution of luminosity of L required for loss of the cross-line under the physical superposition of R and L on the same retina was 84 per cent., while the diminution of luminosity required for loss (or great uncertainty) of the line in the binocular image was 96 per cent. (Sherrington: *Integrative Action of the Nervous System*, page 376). And again, if there be placed in a stereoscope a white field for one eye and a black field with a white vertical stripe running across it for the other, in the combined fields there will be seen a white stripe bordered by black lines gradually fading off into white. The remainder of the combined fields of the black and white will be almost as white as the white stripe (Edridge-Green: *Physiology of Vision*, page 128). Macdougall applies to these phenomena of the prevalence of contours his principle of competition of inter-related nerve-elements for energy, and explains such results as those above recorded as due to the reciprocal re-enforcement of corresponding points with inhibition of adjacent points; for the parts of the field which are brought to both eyes predominate over the parts which are brought to one eye only and the parts which are brought to one eye only are partly or completely inhibited.

And again, as Sherrington points out, if the reaction (nerve)

were initiated at twin points of the retinae *early* in the path along the retino-cerebral nerve-chain to enter mechanisms common to both, then there would necessarily follow, under "alternate" or "synchronous" right-left stimuli, interference, algebraic summation, and so forth. Such a state of affairs, while apsychical in itself, would cause confusion of the sense-reactions of the two eyes. But all experiments point to the fact that such does not exist and experimental results go to "disapprove the existence of any fusion or interference between the apsychical or even sub-perceptual events arising from corresponding retinal points." From his total experimentation, Sherrington concludes:—During binocular regard of an objective image each uniocular mechanism develops independently a sensual image of considerable completeness; the singleness of the binocular perception results from the union of these elaborated uniocular sensations and that the singleness is therefore the product of a synthesis that works with already elaborated sensations contemporaneously proceeding. Hence the cerebral seats of right eye and left eye visual images are separate. "Conductive paths doubtless interconnect them; these are unnecessary for the visual unification of the two images. The unification of a sensation of composite sources is evidently associated with a neurone arrangement different from that which obtains in the synthesis of a reflex movement by the convergence of the reflexes of allied arcs upon its final common paths."

Asthenopia Due to Imbalance of the Extrinsic Muscles of the Eye

DOUBTLESS one of the most difficult things to understand in the study of the effects of errors of refraction upon the human system is the very widely varying results produced by the same error in different individuals. Most

people have errors of refraction of which they are wholly unconscious, and yet we find many eyes, few though they be in comparison to the grand total, which are intolerant of very small errors of refraction. Patients with such eyes are apt to complain of headaches which are not associated with symptoms which can be directly traced to the eyes and are generally skeptical of the fact that their eyes have anything to do with their troubles, since they "see perfectly." But they fail to appreciate that they also see with discomfort. We generally get in such cases a history of a dull headache, not definitely located and as evidenced by the preference for dark rooms or shaded places. Very properly, therefore, when errors of refraction exist, especially uncorrected astigmia, or when glasses are worn which undercorrect the hyperopia or overcorrect the myopia (which is not unknown amongst practitioners) and symptoms of asthenopia are also present, without the existence of any or possibly extremely small imbalances of the extrinsic muscles, the examiner may feel assured of the fact that the asthenopia will be relieved through *proper correction* of refractive errors. One of the underlying failings or weaknesses of the present day practitioner is that he persists in paying attention almost exclusively in his practice to *monocular* visual acuity determinations and that, therefore, in the majority of cases, especially in the young, he is constantly withholding adequate amounts of plus lens power. In the opinion of the writer, any history of asthenopia or photophobia, however insignificant, should direct suspicion first of all to the ciliary muscles and secondly to the extrinsic muscles, and such a history should always make a practitioner chary of prescribing such corrections as —0.25 cyl. ax. 180 or —0.25 spheres, for it is a ten to one chance that ultimately these will be proven incorrectly fitted, not because of inability to see very distinctly but from an increase in the severity of reflex symptoms or in their greater frequency.

We believe that errors of refraction, *per se*, especially those

causing malfunctionings of, or excessive demands upon, the ciliary muscles, are the most common cause of asthenopia. In a fairly considerable number of cases, but constituting a large minority, the symptoms depend on other causes, chief of which are the imbalances of the extrinsic muscles. The presence of a muscular imbalance is not, in and of itself, any reason for intervention, for small muscular imbalances exist in the majority of the eyes of those who do not complain of asthenopia. The reason why such imbalance causes no trouble is obvious: they are physiologically compensated for through the provisions of Nature as developed in the fusion powers. When, therefore, we have a patient who complains of frequent headaches and other reflex symptoms and who has worn correcting lenses which, from all tests—particularly the objective methods—are correct and which are correctly adjusted before the eyes, we should turn to the extrinsic muscles as the probable source of the trouble. Certainly time can be saved and data of great value obtained if the practitioner will get in every case, as a matter of *routine examination*, the condition of muscle balance both at distant and near (reading) points. In the majority of cases we are dealing with *tendencies* to incoördination with ocular symptoms of imbalanced nerve action. Hence every condition which may disturb the nervous equilibrium is to be investigated. An imbalance of the muscles frequently passes away under proper corrections, as for example small amounts of esophoria coupled with hyperopia or hyperopic astigmatism, when correcting lenses are constantly worn. Very often, also, the heterophorias are symptomatic of conditions, both physical and mental, which affect the nervous equilibrium. But there are also many cases in which the imbalance is not symptomatic and in which it is not taken care of through fusion powers, hence is a condition of primary disturbances.

Tests for imbalances of the ocular muscles, as made at any point of fixation, may be accomplished by the three following methods: (1) Those in which one image is displaced, as in

the prism test of von Graefe or the Stevens phorometer, in which doubleness of image occurs through proper procedure, (2) those in which one image is distorted, as in the Maddox rod test, and (3) those in which the image is neither displaced nor distorted, as in the cover test. The writer generally uses either method 1 or method 2, but the latter always in conjunction with method 3. The cover test has the advantage that it has an objective as well as a subjective value. If the patient is orthophoric he will see no movement of the object of fixation when the screen is moved; if he has heterophoria the object will seem to move because the patient's eye has moved to regain the position of fixation necessary for binocular single vision. This test, therefore, when used in conjunction with the Maddox rod test, for example, affords we believe a measure of finding the true imbalance. When prisms correcting a heterophoria are placed in front of a pair of eyes being tested under the Maddox rod method, we are all familiar with the fact that patients often report that the light "jumped" into the streak, or *vice versa*, showing that as these images, which now fall within the fusion areas, approximate the two maculae, fusion occurs. Every practitioner has also had the experience that different methods give different results, and that the same methods do not always give the answer previously afforded by it. It seems to us that the screen test, in conjunction with a distorted image method such as that afforded by the Maddox rod, is a most excellent and trustworthy one. Vertical dissociation of images as given by method 1, when testing for lateral conditions, and lateral dissociations of images when looking for vertical imbalances, are excellent when we are examining persons who have good notions as to when two spots are in a vertical or horizontal line as the case may be.

We believe that duction tests are very important. By them we determine the ability of the muscles to overcome prisms with their bases out, in, up and down; in other words, to adduct, abduct and sursumduct the eyes. Duction tests,

as commonly made with prisms, give data upon the fusion powers at the point at which singleness of vision is maintained. For example, at 20 feet no accommodation and no convergence (practically speaking) are normally demanded and if there are no muscle imbalances present the amount of prism, base out, for instance, will determine the positive reserve fusion at 20 feet. In brief, the duction tests are measures of the ability of a pair of eyes, through the fusion centers, to secure binocular single vision at the point of fixation.

Muscle imbalances may be determined both with and without correcting lenses. This will enable the operator to judge of the immediate effects of the lenses prescribed upon the extrinsic muscular conditions. The writer believes that the test with correcting lenses is the most vital, since it is desirable to know whether or not any marked muscular deficiencies exist after the giving of the correcting lenses as previously determined upon.

Duction tests should be made, we believe, while the corrections are worn. The tonicity tests should be taken into consideration in the determination of the total adduction, abduction and so forth. For example, an esophoria of 3Δ and an apparent abduction of 4Δ would really signify a total abduction of 7Δ, but a negative reserve fusion of 4Δ only.

A Physico-Chemical Discussion of the Mechanism of Formation of Lenticular Opacities

Mabel Weil, A. M.

(Physicist in charge, Radium Laboratory of Dr. Isaac Levin.)

IN a recent paper by Drs. Cohen and Levin (1) some extremely interesting results of the treatment of cataract of the human eye with radium are presented, describing a diminution of opacity in the majority of cases treated. In a physical investigation by Burge (2), the artificial production of cataracts in animals by means of ultra-violet light in the presence of certain inorganic salts is presented. As no attempt has been made, to the writer's knowledge, to correlate these two sets of phenomena, it was considered desirable to discuss these and certain other experimental results from the physico-chemical standpoint. In the course of this study, a theoretical explanation of the cause and of the retrogression of cataracts, from the standpoint of physics, suggested itself to the writer, and will be discussed below.

Use of Radium in the Treatment of Cataracts

Drs. Cohen and Levin present the results of the treatment of twenty-four cases of cataract with radium. In all of the cases treated, gamma rays and hard beta rays from heavily filtered applicators of radium and of radium emanation were used, and in 87.5% of the cases treated, some improvement was noted. In many of the cases, the opacity of the lens diminished appreciably, and in every instance the further development of the cataract was *arrested*. Very interesting drawings, showing the change in the appearance of each of the cataracts treated, are included in the paper. No theoretical deductions are made further than the statement that the rays of radium probably cause cellular changes, but the paper is a clear-cut description of clinical results.

Artificial Production of Cataracts by means of Radium

Burge was one of the first to succeed in producing cataracts artificially. He found that although ultra-violet light has no effect *per se* on the protoplasm protein, the treatment of proteins which have been exposed to these rays, including white of egg and extracts of animal lenses, with certain salt solutions, produces coagulation. Burge has further experimented on living fishes, and has found that those immersed in solutions of these salts, and exposed for long periods to ultra-violet light, develop cataracts, while in cases where the salts are absent, cataracts are not found, and the slight *corneal* opacities which occasionally appear, are transitory. This investigator has also made a chemical analysis of several thousand human lenses which had been removed because of cataract, from inhabitants of the United States and India, and has found amounts of these salts, namely calcium, magnesium and sodium, and in those from India silicon in the form of silicates, far in excess of those found in normal lenses. The quantity of calcium present in the normal lens is less than 0.08% of the ash, while that present in the lenses with opacities is about 15% of the ash. The silicates present in the lenses from India were principally those of calcium, potassium and sodium. Burge concluded that the ultra-violet rays bring about some change in the nature of the lens, so that if there is an excess of calcium or magnesium salts, or of silicates present, coagulation will take place and a cataract will be formed. According to the results of his experiments on paramoecia, this change seems to kill the protoplasm of the cells of the lens.

The opinion has been expressed by many that infra-red rays are a cause of cataract, and recently Vogt (7) has succeeded in artificially producing cataract in the eyes of rabbits by this means. In his discussion of his results, he does not consider that this is necessarily the only method of producing these opacities. Indeed it seems quite conceivable to the writer, that all radiations within the visible region

and somewhat beyond it in both directions, are capable, under suitable conditions, of causing the formation of cataracts.

The writer considers it a matter of some importance to correlate these various phenomena, and has attempted to do this in the following pages. A basis for a possible theory on this subject has also occurred to the writer, and will be presented below. The writer thinks that the contributions of Cohen and Levin and those of Burge and Vogt describe opposite phases of a reversible chemical reaction, and is inclined to believe that the processes described are probably more of a physico-chemical than of a biological nature. Before considering this part of the problem, however, it may be of interest briefly to discuss the action of ultra-violet light in producing cataracts, from the standpoint of photochemical reactions.

Physical Theories to Account for Formation of Cataracts

The phenomenon of a protoplasmic mass, practically unchanged by ultra-violet light until the appropriate salts are added, suggested immediately to the mind of the writer the latent image in photography. Let us see whether the theories of the formation of this image may be extended and applied to this case. One theory of the latent image states that under the action of light, very minute particles of metallic silver are deposited by reduction, the density of the deposit increasing with the intensity of the light, but the amount being in all cases so small as to be invisible. In the developer, these invisible particles are considered to act as nuclei for the precipitation of silver in much the same way that crystallization in a supersaturated solution is brought about by adding a crystal of the substance. A photochemical theory of the formation of a cataract in the eye might take as its starting point the fact that the normal lens contains something like 0.08% of calcium salts, part of which might be precipitated in minute particles by ultra-violet

radiation. As calcium salts in larger amounts gradually entered the lens, an insoluble precipitate of some calcium compound would form, the density of the precipitate varying directly with the density of the original granules, which would depend on the original distribution of calcium salts in the eye. Or, the formation of the cataract might be due to an abnormal original quantity of calcium salts, and the gradual application of ultra-violet light in comparatively small doses. Or, which is far more likely, both the ultra-violet light and the calcium salts are applied gradually and simultaneously over a long period of time, and the precipitate forms gradually when the appropriate amount of radiation acts on the calcium salts. It will be seen at once, that a hypothesis of this kind furnishes an explanation of the gradual maturing of a cataract, as well as of the peculiar striations in the opacities, so beautifully shown in the drawings of Drs. Cohen and Levin. If the calcium salts precipitate about previous minute opacities, the differences in density and unevenness in distribution of opacities might be partly accounted for.

The formation of cataracts may be more fully explained by applying the photo-chemical theory of Allen which is based on the hypothesis that photo-chemical change involves a photo-electric emission, resulting in the production of ionized molecules which are capable of recombining very readily in a different manner. According to this theory, the latent image in photography consists of a collection of ionized molecules, and no chemical change takes place before development. If we consider that the change which takes place in the protein protoplasm of the lens is of the same general nature as the formation of the latent image according to the theory of Allen, the discussion will be similar. We may assume that the ultra-violet rays cause a photo-electric effect in the lens, causing the separation of electrons from the atoms, and that in this ionized state the protein protoplasm of the lens can more readily react with ions of foreign

substances which enter the lens. Now the salts of calcium and the silicates probably enter the lens in aqueous solution and react with the ionized molecules of the lens, forming a precipitate. If we assume selective ionization, *i.e.* the emission of different quantities of electrons in the various layers of the lens tissue or in different parts of the same layer, due perhaps to the selective absorption discussed below, the striated form of some of the cataracts described by Drs. Cohen and Levin can be accounted for. Or, if we assume unequal distribution of the minute amounts of calcium salts present in the normal lens, these will be precipitated when there is sufficient ionization of the protoplasm, and will act as centers of precipitation for further calcium salts. Or, assuming uneven distribution of ions about which the original calcium precipitates, these blotches act as nuclei about which further calcium salts precipitate. It can readily be seen that the maturing of a cataract can be as easily explained on this hypothesis as on the other, in fact, that this latter one may be regarded as a more complete explanation which does not necessarily contradict that of Nernst. The cataract may be considered mature when the reaction has proceeded to chemical equilibrium.

Absorption Spectra of Lens Tissue

In a very interesting paper published by Dhéré (8), the absorption spectra of proteins and albuminoids in the ultra-violet are described. The absorption spectra were found by this investigator to vary with the thickness of the layer used. For very thin layers there is an absorption band somewhere between 2900 and 2600 Å. U; depending on the substance used. The band spreads out with increased thickness in many cases, and as the thickness is increased still further, a second absorption band appears in the ultra-violet, not very far from the visible end of the spectrum. This investigator has studied the absorption bands in many protein substances, and has found that the position of the band varies somewhat

from substance to substance. Burge has investigated the absorption of ultra-violet light in proteins and dead lenses to a sufficient extent to show that absorption of the light is involved in the production of the opacities, and to show in what region of the spectrum this absorption takes place. His results agree fairly well with those of Dhéré as far as the first band is concerned, but he evidently did not look for the second one. In his work, the radiation from a quartz mercury lamp was passed through a quartz spectrograph and focused on an extract of pig lenses to which calcium chloride solution had been added. The following spectral lines of coagulated protein appeared:—

λ2540	after	an	interval	of	50	minutes
λ2650	"	"	"	"	65	"
λ2800	"	"	"	"	120	"
λ3020	"	"	"	"	120	"
other lines	"	"	"	"	200	"

One half of the slit of the spectrograph was then covered with the cornea of a rabbit and it appeared that the cornea transmits wave-lengths as short as λ2970 which are effective in producing those changes in the protein of the lens which makes coagulation possible when calcium salts or silicates are present in sufficient quantity. Some results of Schanz relative to absorption spectra of proteins will be considered further on in this paper.

We have now correlated some of the striking phenomena connected with the formation of cataracts. Experiment has proved that either infra-red or ultra-violet radiation may produce these opacities, but the facts available regarding the former method are very meager. In regard to the latter we know that the presence of certain salts in the lens has thus far been found requisite, and that the absorption of light of certain fairly definite wave-lengths is most effective in producing this result. The writer has suggested a physico-chemical hypothesis to explain the observed phenomena on the basis of the above-mentioned experimental results.

A Reversible Chemical Reaction

How can we interpret the opposite reaction, namely, the removal of the opacity by means of radium rays? We may consider that the chemical equilibrium is disturbed by further ionization. Furthermore, we can assume that ionization takes place in the calcium precipitate, so that some of it goes into solution.

The fact that the opacity probably produced by ultra-violet light clears up somewhat in many cases in the presence of radium rays does not in itself prove that the reaction is reversible. But this is rendered highly probable by the fact that in certain cases radium radiations do not clear up the opacity. In such cases the rays probably bring about chemical equilibrium, and without them the precipitation would continue and progress. So, if the radium radiation is sufficient to displace the equilibrium, the reaction will proceed in the reverse direction, sometimes only partially, as a state of equilibrium is again reached when more calcium salts enter the eye and are deposited there. It is quite conceivable that, in certain cases, the radium radiations might disturb the equilibrium, and then the cataract might retrogress to a certain extent, and then the ingress of new calcium salt solutions, together with possible further exposure to ultra-violet light, might cause further deposition, again reversing the reaction in the original direction. There seems to be no experimental evidence whatever on this point, and clinical experience as well as physical laboratory experiments are required to test it out.

From the physical standpoint, the explanation would have to consist in the production of a chemical change by secondary β rays or secondary γ or X rays produced by the primary γ rays of the radium. This type of reaction is but very slightly understood, but undoubtedly has ionization as its basis.

The question of the action of γ rays and ultra-violet radiation has been quite fully discussed by Doelter (3) in an

empirical way. Doelter divides his observations into several groups, mentioning cases where radium and ultra-violet rays act in the same direction, where they have no effect, and where they act in opposite directions in producing chemical and physical change. He discusses the matter chiefly from the standpoint of changes of color brought about by these agents in organic and inorganic compounds. Among the cases where these two agents have opposite effects, certain instances are of great interest. Doelter states that radium and ultra-violet light have opposite effects in the coloration of precious stones and certain other minerals, and that the blood of the rabbit becomes darker in color under the action of radium, but lighter again under the influence of ultra-violet rays. Doelter also remarks that radium in certain cases changes colloids into crystalloids, and that occasionally the opposite is observed, but that this is more common under the action of ultra-violet light. He states that under the influence of ultra-violet light, the size of the particles of some substances, as observed with the ultra-microscope, is increased, and that finally coagulation sets in. He describes the same type of phenomenon in the case of silver salts under the action of radium, but states that in the case of these rays, the effect is generally opposite. Thus these empirical results would tend to lend support to a theory of reversible chemical reactions.

Certain Chemical Effects of Radiation

An interesting piece of chemical work was carried out by Schanz (10) relative to the chemical nature of the changes brought about by ultra-violet light in protein substances, including lens tissue. This investigator extended the work of Dreyer and Hansen and of Chalupecky in showing that under the influence of the rays alone, the protein becomes less soluble, in fact that albumen changes into globulin and finally that some coagulated protein is produced. He determined the percentage of the less soluble products formed,

both in the case of lens tissue and of white of egg. In no case was he able to produce as large a quantity of coagulated protein as Burge. However, he proved the existence of the less soluble products by means of a delicate chemical reaction and found similar changes in the blood serum. He reached the conclusion that the sclerosis of the center of the lens can be brought about by the ultra-violet rays in ordinary sunlight. He discovered a qualitative law of change of absorption of ultra-violet light in the lens. This absorption increases with the age of the person and is practically complete after the 50th year. The lens fluoresces under the action of the rays, the fluorescence extending from the blue region of the visible spectrum to beyond $\lambda 3000$, being strongest at $\lambda 3850$. This agrees approximately in position with one of Dhéré's absorption bands.

It is noteworthy that in the experiments of Schanz, in the case of white of egg, only a very minute amount of coagulated protein was produced by the ultra-violet light alone, although an appreciable amount of globulin was formed. In the case of the eye lens tissue, however, a far larger proportion of coagulated protein was produced at the end of four hours' radiation, and the original amount of globulin decreased materially. This latter is an entire contradiction to the results obtained by Burge, who found no appreciable coagulation in lens tissue or of white of egg at the end of thirty hours' radiation without the aid of any chemical agents. The experiments with white of egg performed by the two investigators appear to check up pretty well. The question might therefore be raised in the case of Schanz's work with lens tissue, whether abnormal amounts of calcium salts or silicate were present in the lenses studied by him. This point evidently was not at all considered, and he gives no indication, in his account of his work, whether or not he was working with *perfectly normal* lens tissue.

Some interesting observations of chemical effects of radium were made by Hardy (11) and by Frischauer. The

former noted the action of *alpha* rays from radium on the coagulation of globulin. In the presence of acetic acid the globulin was more completely dissolved, while in the presence of ammonia the solution became opaque and coagulated. Frischauer noted that the crystallization of sulphur was greatly precipitated by the *beta* rays of radium which produced additional nuclei for crystallization.

Effect of Radium on the Lens

There is very little experimental evidence relative to the physical action of radium on the lens of the eye. It is known, however, that the lens fluoresces under the action of radiations from radioactive bodies. This would suggest the absorption of the gamma rays and probably also of the hard beta rays with the accompanying ionization and production of secondary gamma rays. If the chemical nature of the lens changes with age, as indicated above, the difficulty of the explanation is very greatly increased. In case it should in the future actually be shown that well defined cataracts can be produced by means of ultra-violet light, where no salts of calcium or no silicates are present, the latent image theory presented above would probably not hold for this type of cataract, but a somewhat similar theory of chemical action produced by an electron discharge would take its place. It is also possible that a similar theory might explain the production of opacities by means of infra-red rays. However, there is no proof that all cataracts are caused by the same mechanism; in fact, the evidence at hand might suggest several. That the rôle of the radium radiations, however, is to reverse a chemical reaction or disturb chemical equilibrium, seems to be the most plausible assumption at present.

Effect of Radiation on Opacities of the Cornea

Some very interesting clinical results were obtained by Sulzer, who partially cleared up an opacity of the *cornea* by

means of ultra-violet radiation. The effect, however, was comparatively slight, and after six applications no further improvement was obtained. Then radiotherapy was tried, and after nine applications the opacity had almost disappeared. Burge obtained some interesting results of a somewhat different nature relating to corneal opacities. In his experiments on animals he found that such opacities sometimes occurred to a very slight degree under the influence of ultra-violet light, even when no calcium or other salts were present, but in such cases they persisted but a short time, and cleared up by themselves. Where such opacities occurred, however, in the presence of calcium salts, they were far more persistent. A partial clearing up due to additional photo-therapy was not observed by Burge, in fact, apparently, was not sought by him. These results ought to be checked up with those of Schanz on the lens by very careful experiments.

Dr. Levin has stated to the writer that judging from his *clinical* experience with the ultra-violet radiations and the gamma rays of radium, the two types of rays appear to have opposite *biological* effects on animal tissues. The writer is of the opinion that in the case of cataracts, however, the biological action is very distinctly subsidiary to the physical.

Conclusion

As can readily be seen by the above discussion, this subject is of considerable importance, and has not received the experimental study which it deserves. The beginnings, both experimental and clinical, however, show that results of the utmost interest should be forthcoming. We do not yet know definitely which wave-lengths in the ultra-violet are most effective in producing opacities, or which agent is more effective, the ultra-violet or infra-red. The mechanism of production of cataract by infra-red rays is entirely unknown. The cause of the presence of calcium and magnesium salts and of silicates in the lens of the eye is an interesting problem

in metabolism which deserves the attention of some skilled physician or biologist. The action of β and of γ rays in producing physical and chemical change also deserves much further study. Finally, the entire question as to whether it is the wave-length of the radiation used which is of primary importance, or the amount of ionization or other secondary effects, must be thoroughly investigated both in the physical laboratory and the clinic. It will be noted that this paper does not touch upon the pathology of cataracts or their formation by *purely chemical* means, but that the subject is discussed solely from the standpoint of the effects of radiation.

The above considerations of the writer are but suggestions based on admittedly scanty evidence, and must be accepted or rejected solely on the basis of future experimentation. The writer is now making preparations for beginning such experimental physical research, which will be discussed in a later paper.

Radium Laboratory of Dr. Isaac Levin,
New York City.

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Cerebral Malprojection of the Spatial Point Due to Unconscious Habit

Eugene G. Wiseman, Opt. D.

Introduction

WHEN testing the tonicity of the ocular muscles it is customary to place the fusion-check (red glass, Maddox rod, double prisms, etc.) before the right eye. Under ordinary circumstances it may then be assumed that if orthophoria exists, the red light, light streak, etc., as seen by the right eye will be superimposed over the white light as seen by the left eye,[1] while exophoria will cause the red light to appear to the left of the white light, and esophoria will cause it to appear to the right of the white light.

However, such is not invariably the case, and the writer wishes to point out that there exists a small percentage of cases in which the red light, as viewed by the right eye, is interpreted by the patient as being located to the *right* of the white light seen by the left eye while it is visibly evident that the right eye is *deviating outwardly* (exotropia) and rays from the original source are therefore falling upon the temporal portion of the retina.

This is directly contrary to our knowledge of anatomy and physiology and yet it is not due to an actual hallucination on the part of the patient, nor can it be attributed to any lack of intelligence.

Though it may not be necessary, it will be wise to present a few elementary facts regarding the anatomy of the visual paths and the physiology of vision so that this hypothesis will be clearly and easily understood without necessitating special work by way of verification on the part of the reader.

[1]This is not strictly true, for in actual orthophoria (parallelism of the visual axes) the red light will appear deflected to the left of the white light for a distance precisely equal to the interpupillary distance of the two eyes.

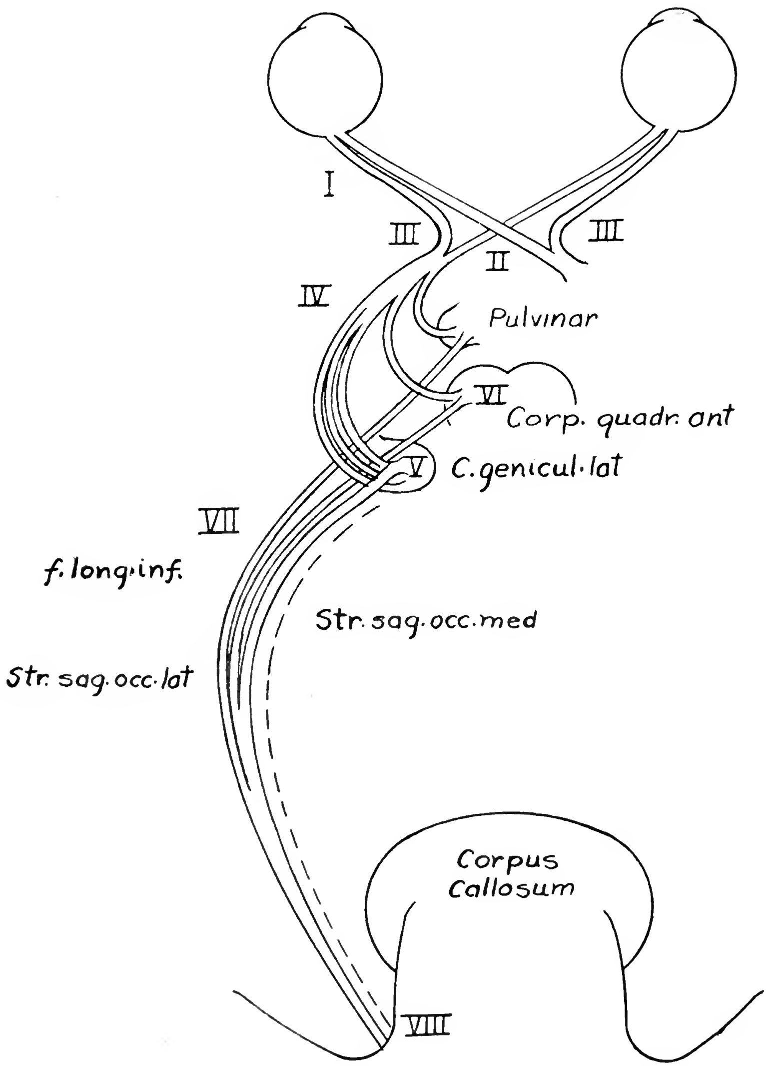
I
III
II
III
IV
Pulvinar
VI
Corp. quadr. ant
V
C. genicul. lat
VII
f. long. inf.
Str. sag. occ. med
Str. sag. occ. lat
Corpus
Callosum
VIII

Fig. 1

The transformation of the purely physical phenomenon of light into the psychical phenomenon of sight begins when the wave of light strikes the retina of the eye. The resultant agitation is transmitted to the optic nerve, carried by it to the external geniculate body, the pulvinar of the optic thalamus and the anterior quadrigeminal body from which it is relayed to the cuneus of the occipital cortex and there transformed into the psychic sensation of sight.[2] This would be a comparatively simple physiological process were it not for two essential factors, to wit, the image upon the retina is an *inverted* image, and *two* eyes are involved, the images of which must coördinate if economic binocular functioning is to follow. The simple Fig. 2 illustrates the first point, it being plainly evident that even as the arrow is inverted, so will all parts of the visual field be reversed upon the retina. It will be noted and remembered, then, that the *superior* part of the field falls upon the *inferior* part of the retina, the *inferior* field upon the *superior* portion of the retina, the *left* field upon the *right* part of the retina and the *right* field upon the *left* part of the retina. It is evident, therefore, that a ray of light falling upon the *inferior* portion of the retina is recognized as emanating from the *superior* part of the visual field, and the same reasoning applies to other portions of the retina.

[2]Knapp Medical Ophthalmology.

Fig. 1. Topographical diagnosis of visual path lesions. [From Knapp, *Medical Ophthalmology*.]

I Optic nerve. Homolateral amaurosis. Homolateral loss of direct, contralateral of consensual pupillary reaction ("Reflex Taubheit"). II Chiasm. Median line. Bitemporal hemianopsia (acromegaly, dystrophia adiposogenitalis). III Only in bilateral affections. Bilateral nasal hemianopsia (arteriosclerosis, lues. trauma). IV Tract. Hemianopsia of definite character including macula, hemianopic iridoplegia (hemiplegia, same-sided ptosis (Wernicke's syndrome). V If only the ventral or dorsal part of the geniculate body is affected then quadrant hemianopsia. VI Hemianopic iridoplegia. VII Bilateral homonymous hemianopsia (in socalled carrefour sénsitive with hemihypaesthesia and hemiplegia; capsule lesion). VIII Right like (7). Bilateral cortical-blindness. Left, soul-blindness.

When two eyes are employed, complications arise, for it is evident in Fig. 3 that, while rays emanating from the *left* visual field fall upon the *right*, or *temporal*, half of the right

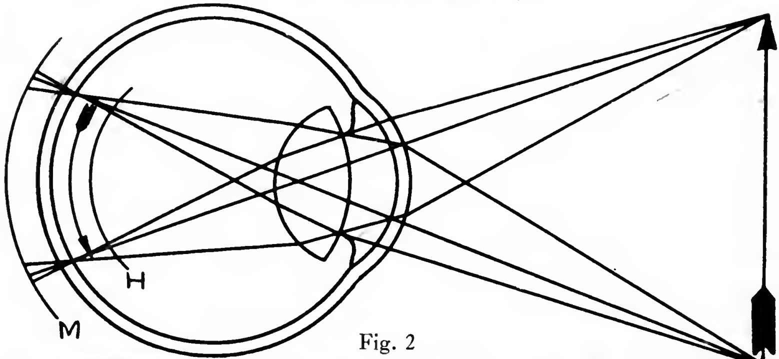

Fig. 2

retina, at L_1, rays from the same object fall upon the right or *nasal* half of the left retina, at L_2. The superimposition of these two halves so that a single image results is a com-

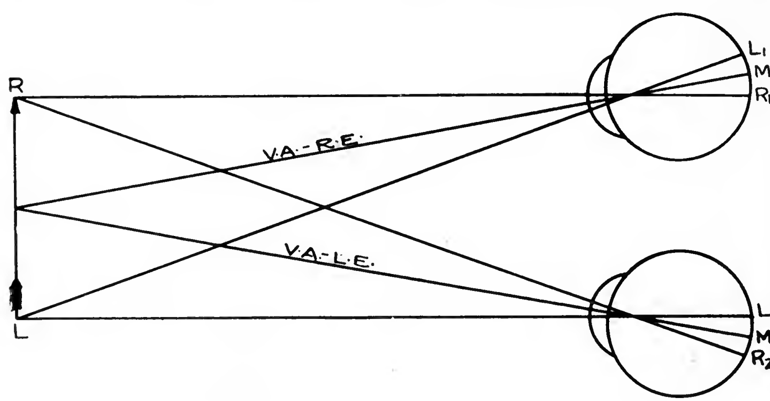

Fig. 3

plicated process and is brought about in the following way: The retina, which is merely a projection of the brain, may be schematically (not literally) considered in this study as

consisting of innumerable fibres, the ends of which, near their termination, leave the general retinal curve and are directed to approximately the center of the eyeball. Their schematic appearance would then be that of the bristles of a hollow spherical brush with the bristles pointing inwardly. Each fibre receives a separate impression of the outer world, and that impression is wired, as it were, to its *own individual cell* in the cortex of the brain and it is there interpreted in accordance with its intensity and its relationship to the impressions received by other cells.

In the interests of binocular single vision it is essential that the impression received by the right or temporal half of the right retina be practically identical with the impression received by the right or nasal half of the left retina, and so it is assumed that each individual fibre in the one half has its counterpart in the other half, the two fibres later being brought to a termination in the brain either in two cells in close juxtaposition or in the same cell. The writer is inclined to the two-cell theory.

In order to accomplish this end and to overcome the physical barrier, the two retinae are anatomically divided into two halves. The fibres of the right, or temporal half, of the right eye pursue their course through the right half of the optic nerve to the optic chiasm, to the external geniculate body and from there are relayed to the right half of the occipital cortex.

The fibres of the left half remain on the left of the optic nerve until it reaches the chiasm and there they cross over to the left optic tract and continue their course to the external geniculate body on the right side of the optic tract, terminating ultimately in the left occipital cortex. In the same manner, the fibres in the right half of the left eye cross at the chiasm to the right tract and join the fibres from the right half of the right eye, and the fibres from the left half of the left eye remain on the original side. In this way the two right halves are linked together in the right hemisphere,

and similarly the two left halves in the left hemisphere. It may be added that the halves overlap in the vertical macular plane, so that the macula is represented by both halves in each hemisphere, and if one hemisphere or optic tract is destroyed, macular vision will still be possible. This would be true even in bilateral hemianopsia—blindness in both outer or both inner halves of the retina.

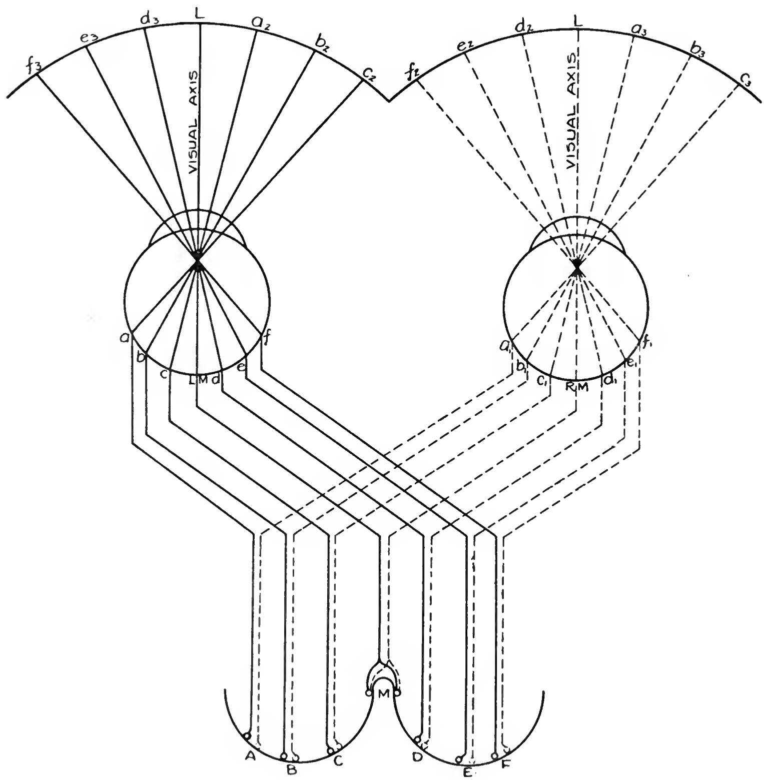

Fig. 4

It is evident that when the visual axes are parallel, as in Fig. 4, the light at L (an infinite distance) will fall upon each

macula, and the sensation ultimately arrive at M in the cortex. Similarly an object at d_3, e_3 or f_3 sending light to d, e or f will send rays also to d_1, e_1 or f_1, and the sensation aroused will be "wired" to D, E or F.

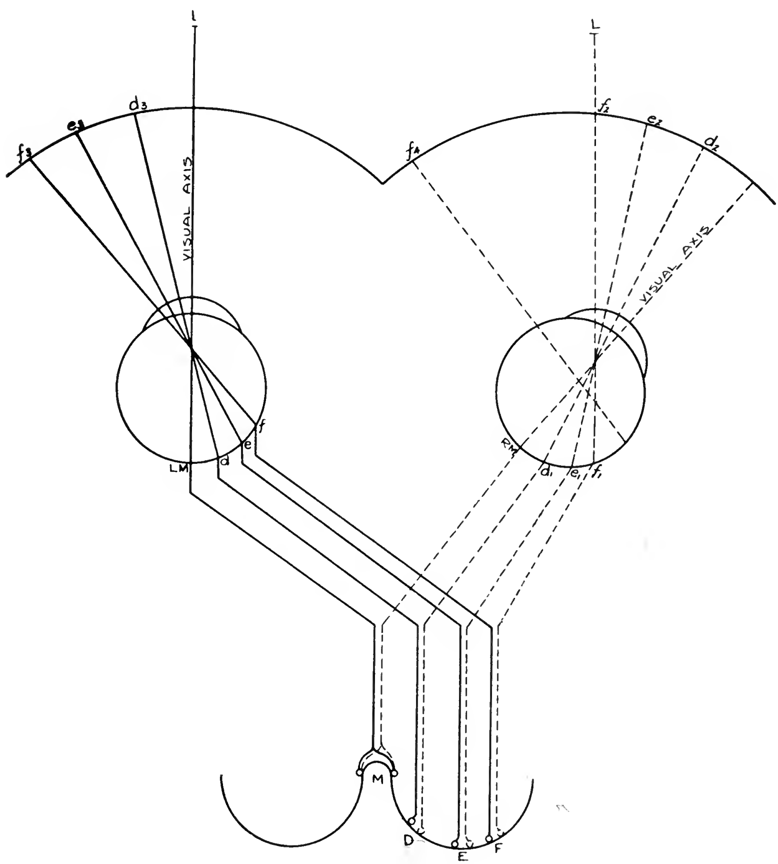

Fig. 5

Therefore light falling upon, say, f_1 is recognized by the brain as having emanated from an object located in the left

visual field of the right eye because that particular cell or fibre of the retina is connected with its individual cell F in the brain, and the brain will usually recognize a vibratory disturbance of this cell as caused by an object situated at f_2. If this philosophy were inflexible, it would follow that if the right eye turned outwardly so that light from L fell upon f_1 as in Fig. 5, the brain would recognize the sensation as having originated at f_4 because the light at L, which has not moved at all, has stimulated that brain cell which, spacially projected, corresponds to f_4. This is why, in right exophoria with the red glass before the right eye the red appears to be located to the left of the white light as seen by the left eye. But such a condition is not invariable.

In February and March, 1919, the writer encountered two cases in which the red light, in high exophoria, persistently appeared to the right of the white light. In fact, in one of the cases, as the eye turned outward, the red light appeared to the patient to travel to the right, just contrary to the customary action. (Not due to internal reflection.)

Case I

The first case observed was that of a woman who had been examined by the writer in 1912 when she was 26 years old. She was then given

O D $+.50 \bigcirc -.75$ ax. $165° \bigcirc 4^{\Delta}$ Base in d. ax. 165°
O S $+.50 \bigcirc -1.00$ ax. $0° \bigcirc 4^{\Delta}$ Apex out d. ax. 165°

The muscular condition as noted at that time was hyper-exophoric, 15Δ ax. 165. The writer has a vague recollection that at that time or at a subsequent examination, the patient gave the same contradictory evidence as at the last examination, but there is no note to that effect and it seems unlikely that the condition existed in 1912 because of the explicitness of the notation regarding the muscle condition then.

Another examination was made in January 1917 at which time the patient was given

O D + .75 ⊃—1.00 ax. 175° ⊃ 3△ Base in d. ax. 145°
O S + .75 ⊃—1.25 ax. 175° ⊃ 3△ Apex out d. ax. 145°
Crookes, A shade. V. A. O U 20/20

It is highly probable that the contradictory condition was first noted at that time and disregarded as an individual idiosyncrasy of little or no consequence. The patient again called in Feb. 1919. She complained of pain in and above the eyes and "in the back of the neck," a typical symptom of eyestrain. The refraction was found to be precisely the same as in 1917. The muscle condition was confusing, there being a noticeable divergence of the eye under the red glass test, sometimes increasing actually or relatively when near objects were fixed; yet the red light persistently appeared to the right of the white light, the common indication of esophoria.

Repeated tests yielded no different results. The only way in which it was possible to measure the state of equilibrium of the muscles was to exclude one eye, the red glass having been removed, and have the patient fix a bright light across the room. Then the cover was shifted to the other eye and the approximate amount of excursion of the uncovered eye's movement to fix the light noted. Prisms were applied and the test repeated until no movement of the eye could be observed. In this way it was determined that the prisms given in 1917 were still approximately correct. It then became a problem to account for the very evident symptoms of eyestrain. With the refraction properly corrected, the muscle imbalance neutralized apparently as well as possible and the accommodation normal, there seemed to remain only one avenue through which the cause could be sought, namely, the neuricity of the extrinsic muscles. Or, one might broadly say, the ability of the extrinsic muscles properly to perform their functions. Duc-

tion test revealed only 16Δ of adduction, plus the amount of exophoric error, the eye being balanced in the horizontal plane with a 3Δ prism, base-apex line at 90 while this test was made.

It seemed reasonable to suppose that this condition had something to do with the symptoms from which the patient was suffering. It is apparent that an exophoric pair of eyes which had only 16Δ of adduction *without* prism correction would have only about 20° *with* the approximate correction of 4Δ, and since 20Δ of internal verting power is normally the minimum required, it is plain that the patient was constantly calling upon the eyes for their maximum strength. A constant demand for the maximum effort is practically always disastrous. That this patient was exercising such a demand is evidenced by the fact that she could read for but a few moments at a time, and the result for even this short period of application was a severe frontal and occipital pain. At any rate, there remained nothing else to which her symptoms could be attributed, and so it was determined to build up her adduction power.

Exercises thrice weekly for 4 weeks, in addition to the daily use of exercising prisms at home, brought the adduction up to 45Δ in addition to the exophoric error. This amount of prism power could be overcome almost instantly when suddenly interposed before the eyes, a most unusual exhibition of fusion power and activity. The first few treatments produced very disagreeable results—headache and eye-ache, vertigo and nausea. The patient became most discouraged and wished to discontinue them but was prevailed upon not to do so. At the 5th treatment she stated that the pain in the back of the neck was almost all gone. At the 10th there was *complete* relief from *all* symptoms. With a tremendous effort she could now fuse through 45Δ of prism power, and so subsequent treatments were merely for the purpose of firmly establishing the power of the fusion faculty, and increasing the flexibility and rapidity of action.

In the course of the treatment of this case unembellished notes were made as follows:

1 Much better results were obtained by using square prisms held loosely in the hand than with the rotary prisms.

2 When treatments were first instituted, the patient, as stated, with the red glass before the right eye, would see the red light to the *right* of the white light, even though the eyes were noticeably divergent. If the left eye was then covered and the patient's attention directed specifically to the red light, the right eye remained motionless. After the 8th treatment, however, under the same circumstances, the patient's right eye made an excursion to the *left*, thereby proving that the false macular (cerebral) area could no longer compete with the true macular area which had apparently become increased in efficiency through the calisthenics.

3 After the 10th treatment, when the right eye was covered by the red glass for a few minutes, the patient being told to relax in all respects, the *red light* suddenly appeared *to the left of the white light*, this being the first occasion that this occurred. It almost immediately re-appeared to the right again. It should be noted that during the process of change the patient's mind was confused and she did not seem to be able to see the light actually shifting from the one side to the other.

4 By coaxing with a prism, base in, to the approximate extent of the patient's error, it became easier to cause the red light to appear to the left of the white light *at the instant the prism was removed* and finally it would stay there for an appreciable length of time.

5 Shortly before the conclusion of the treatments it became reasonably easy to cause the red light to *float* from the right to the left of the white where it remained. The defect as measured under these circumstances amounted to 4^{Δ} of hyperphoria and 6^{Δ} of exophoria, the combination equalling 9^{Δ} of hyperexophoria at 150°.

6 Changing the red glass from one eye to the other made no difference in the contradictory results.

The consultant wore the last-mentioned prescription until Dec. 11, 1920 at which time she reported occipital headache and a local irritation of the eyes. A re-examination revealed practically the same refractive condition as before, $2\frac{1}{2}\Delta$ to 3Δ

of right hyperphoria, and *complete disappearance of the lateral muscle imbalance.* She recognized the red light as being in its proper place. Correct spheres and cylinders were given, together with a 2Δ prism base up, left eye. Six muscle treatments were given and her symptoms completely disappeared.

Case II

The other case was that of a young man 20 years old who presented himself in March 1919. His complaint, as noted at the time he called, was that his left eye turned out occasionally, and it also blurred for distance vision. His refraction was,

O D	Normal.	V. A. 20/20
O S	—1.75 —.75 ax. 0°	V. A. 20/25

The muscular condition showed about 30Δ exophoria, and it was impossible to measure the defect accurately as he also saw the red light to the right even though the eyes were widely divergent. In fact, after wearing lenses for two weeks—lenses half a diopter minus stronger than actual defect were given in order to stimulate the action of the ciliary and internal recti—while the patient could maintain parallelism even when the red glass covered the right eye, during which time the red and white lights coincided, a relaxation of the muscles, allowing the eyes to diverge, resulted in a movement of the red light *to the right.* In addition to his spherical and cylindrical correction this man was given 5Δ prisms, bases in, each eye, in order not only to relieve the enormous strain upon the internal recti muscles but to upset the abnormal relationship between the physiological and psychological spheres which was controvening the intentions of Nature.

With reference to the latter, if, as in Fig. 5, a ray of light from L falls upon f_1 and is recognized as coming from L instead of from f_4, there surely is a perversion of natural laws

and it should be reasonably easy to upset the unnatural situation by deflecting the ray from L so that it falls upon, say, e_1 or d_1. This would necessitate an entirely new combination in the brain, and while it is in the process of readjustment it should be possible to guide it so that it finally conforms to natural conditions.

The patient returned April 30th, 1919 and was given three muscle exercises weekly for one month. Following are the notes accumulated during this period:

4/30/19. With right eye covered with red glass the red and white lights were together until right eye relaxed, then red light appeared to right. But in order to really *see* the red light when the left eye was covered it became necessary to make a conscious movement to the left.

5/2/19. With prisms 20^{Δ}, base out, it was impossible for the eyes to see double even though there was actual or relative divergence. The eyes would shift backward and forward to see each single light but diplopia did not exist. The only way diplopia could be brought about was with the prisms placed vertically or base in.

5/5/19. Exercises were first given with prisms 14^{Δ} base out, but it was finally noted that the eyes were actually divergent during these treatments, and so the value of the treatments was actually lost. This seemingly was because the power for fusion in a certain area of the brain actually was lost or submerged. There also were no symptoms of strain when these treatments were given. However, when the amblyoscope was used the strain was marked. The patient (with his correcting lenses on) could see double (eccentric circles used) with the instrument divergent, parallel or convergent to the extent of about 15^{Δ}. After that (above 15^{Δ}) he saw singly and with perception of depth. After 30^{Δ} he saw singly but *without* perception of depth, showing that the eyes turned outward and fusion power was lost.

5/7/19. Now sees double with amblyoscope set at 0^{Δ}, fuses at about 10^{Δ} and has perception of depth until 25^{Δ} reached. After 25^{Δ} object "flattens" and cannot see double either, though he says he "cannot see double when he looks with both eyes" although he sees another object to the side when he shifts. He suffers, then, a total disregard of objects with the one eye when looking with the other.

Today red light for the first time appeared to the left—*moved* to left. This occurred after using prism base down before right eye for a time. Exophoria as measured equals 30$^\Delta$. At first the red suddenly appeared to left, showing that the mind suddenly decided to disregard false image on right and concentrate on left image. Afterward, when the eyes were parallel, the red *moved* to left as eyes were relaxed[(1)]—in the usual manner. It will be remembered that at first the red appeared to move to right as eyes were relaxed. Now, too, the left eye perceptibly turns in when prisms, base out, are applied. It should be mentioned that patient wears pad over right eye two hours a day, thus compelling use of left eye—the divergent eye.

5/9/19. The patient now saw the red light immediately to the left of the white—about a yard. It is hard to exercise the muscles, though, because the fusion power is so slight. He perceptibly fuses 7$^\Delta$ to 8$^\Delta$ prism but when more is applied the left eye seems to turn out a bit and stay there. Must use 4$^\Delta$ base out, each eye, for a time.

5/11/19. Used 11$^\Delta$ of prism today and with apparent ability to overcome them. In using amblyoscope, *depth* was maintained from about 7½$^\Delta$ to 17½$^\Delta$ at first. Then it increased to 20$^\Delta$. When the instrument was set at 22½$^\Delta$ the object was at first *flat*. Then it alternated from flat to depth and back again, never staying stationary.

5/16/19. Fuses L and F into E at 35$^\Delta$.

5/19/19. Fuses L and F into E at 45$^\Delta$. Fused circles to 35$^\Delta$. (Perception of depth at this point.) It should be noted that patients nearly always seem to converge more with the amblyoscope when they handle it themselves. There is evidently more intelligent co-ordination and concentration.

5/23/19. Used phoro-optometer this time with nothing before right eye and—1.75 before left; no correcting prisms. Overcame 45$^\Delta$ to 50$^\Delta$ base out, in addition to error.

After the 12th treatment this patient was discharged as relieved of all symptoms complained of and with a pair of eyes functioning as economically as their errors would permit.

Conclusions

The writer's natural conclusion as a result of these studies is that the fault of the condition lay either in the cortex of

[(1)]Patient has the ability to bring eyes to parallelism and to relax to a divergent state.

the brain where the retinal fibres or their continuations ultimately terminate, or in the psychic sphere of the brain. The latter seems more probable. Certainly the fault could not be in the retina because the retina of each eye functioned normally when used singly, or, indeed, when used in conjunction with the other for distance vision, nor could it be in the optic nerve anterior to the external geniculate body, the thalamus and the anterior quadrigeminal body.

Since the latter three centers have rather well-defined connections, they also may be ruled out as the seat of the fault. To quote Knapp in this particular:—"The external geniculate body is only a neuronal relay station in the passage of the visual fibres destined for the cortex. The anterior quadrigeminal body is a reflex center. It directs its neurons to the centers governing the movement of the iris and the other sensory and motor system which are in connection with vision. The pulvinar sends possibly a few fibres to the cortex, but its principal function consists in connecting the visual apparatus with the other sensory and motor systems, particularly those which govern the expression of the face. Schematically one may say that the geniculate body is related to cortical and conscious vision; the quadrigeminal body to the reflex movements of visual origin; the pulvinar to automatic movements of visual origin, the latter two only giving unconscious perception. An animal deprived of its occipital lobe follows the light, evades obstacles, has normal pupillary reflexes, but does not recognize anything. In the lower animals these two centers are very much more developed than the first. In the more intelligent animals their size diminishes while the areas of the cortex and of the external geniculate body increases.

"The first, the external geniculate body, as has just been stated, is the chief primary optic center, the true betweenbrain of the optic path. It receives the greatest number (80 per cent) of the fibres from the tract and sends visual stimuli through the fibres of the optic radiation to the

visual sphere. According to Henschen, the individual optic bundles retain a definite position even in this ganglion and it can be said that the retina is projected on this ganglion. The dorsal segment must, therefore, correspond to the dorsal retinal quadrants of both eyes. Destruction produces constant and permanent quadrant hemianopsia in the lower halves of both fields."

But it cannot well be the projection of the retina on the external geniculate ganglion which represents the faulty area, for then it would seem that the faulty interpretation would exist as notably when either eye was used singly as when both were used and one covered with a red glass. For precisely the same reason the area in the cortex which represents the termination of the optic fibres, and which Knapp says may be regarded as a definite negative of the retina, can likewise be regarded as doubtful. A lesion in this area produces blindness in a corresponding part of the retina, so the connection must be more or less direct and permanent—an actual anatomical and mechanical union. And so, since it is improbable that any part of the physical visual path is fundamentally at fault, the seat of the anomaly must be sought in psychical sphere or sense.

It is easy to construct a hypothesis upon such premises. We are all aware of the mind's ability completely to ignore everything save a particular point of fixation. Yet the physical image of everything surrounding this point must be photographed on the retina, the geniculate body and the optic cortex. The final connection, save at one point between the cortex and the psychic sphere, has been suspended.

In the cases under consideration it seems reasonable to suppose that the mind unconsciously assumed a habit of wrong interpretation of direction. This would be rather natural under the circumstances and in accordance with economic functioning of the nervous system. It should be noted that the eyes in both cases were subjected to an

enormous strain, the one pair being compelled to overcome, in earlier years at least, about 12Δ of exophoria and 3Δ of hyperphoria, and the other 30Δ of exophoria. It being impossible for them to maintain binocular vision at all times, they easily fell into the habit of diverging, relatively or actually, when near objects were fixed, and finally they diverged part of the time when distant objects were fixed.

Now, the brain abhors diplopia and it will do strange things to avoid it. One of these is simply to ignore completely the image of the mal-directed eye. In such cases the eye often undergoes atrophy and becomes a more or less useless member. But this is sometimes too great a sacrifice to make and so some other provision must be made that each eye is occasionally used and normal acuity of vision maintained. This the writer believes is done by automatically severing the relationship between corresponding points of the two retinae when divergence occurs and also severing their *simultaneous* connection with the psychic sphere. At the same time the mind wilfully recognizes a relationship between two non-corresponding points, and associates the two together to the end that *conscious* diplopia may not exist. This is accomplished by becoming superlatively conscious of the peripheral image at f_1, associating it with the left image at L M, and ignoring the right image at R M. It is easier to understand this when it is considered that the disregard of the right image at R M is a very simple matter, automatically taking place, for instance, when we examine with either the skiascope, the ophthalmoscope or the microscope, the image of the unused eye being entirely obliterated from the mind. It may be further facilitated by assuming that the transference of vision from the physical field in the cortex to the psychic field is accomplished by vibration, each cell vibrating according to the impulse it receives, its position in regard to the spatial field and its relation to other cells.

It seems necessary further to assume that the writer's two-cell theory is correct, in contrast with the one-cell theory

of Savage. That author "believes he uttered the truth when he taught, some years ago, that the secret of corresponding retinal points is common brain-cell connection; that one macula corresponds point for point with the other macula only because these corresponding points have, going from them, two fibres which meet in the optic tract and go, side by side, back to the same cuneus, to terminate in one common cell in the visual center. Corresponding points in the two vertical meridians, likewise corresponding points in any two oblique meridians similarly related to the vertical and horizontal meridians and to the maculae, must have common brain-cell connections." Contrasted with this view is the writer's—that instead of having a common cell connection, each fibre has its own cell connection but the two cells from corresponding points in each retina are situated side by side and when they vibrate simultaneously and in unison the brain recognizes that binocular single vision exists, and when there is conflicting vibration, diplopia or monocular vision is present. Now, in the present consideration, would it be at all strange if the almost constant stimulus of the nerve fibre at f_1 so controvened the intentions of Nature that the mind, for the sake of harmony, chose to suppress all points of the visual field except that corresponding to f_1, and interprets the vibration at f_1 as corresponding to the vibration at L M?

Since the mind can totally suppress the entire visual field and interpret it as non-existent under certain circumstances, it seems not beyond its powers to interpret wrongly under certain other conditions. Therefore, when a red glass disk is placed before the right eye, there is brought about an actual suppression of all of the field except the single bright spot and since this is precisely the condition which exists when the mind deliberately suppresses all of the field except the point f_1, the point F in the brain is the only point which remains in action. Hence, it is still associated with L M and therefore the red light is interpreted as being located with the white light.

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Abstracts and Reviews

Recognition of Detail

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(There is considerable of value in this paper in the way of summaries of conclusions as to the limits of visibility, extinction of color, visual acuity and brightness, and contrast in illumination.—ED.)

Limits of Visibility

INVESTIGATIONS on the quantity of light necessary to produce the sensation of brightness have been made in two ways—by measurement of the *illumination* necessary to make an extended object visible and of the candle-power of a small source of light which is just visible, but very little attempt seems to have been made to co-ordinate the results, or to consider the significance of the actual values obtained. Aubert, among others, has measured the minimum illumination (threshold value) for an eye fully adapted to darkness. In these observations a white extended object was just visible when the illumination was equivalent to one candle at 200 to 250 metres. Sir W. Abney's measurements confirm and extend these results; his observations were made for each part of the spectrum and they give 16×10^{-6} metre candle for the minimum illumination for the recognition of light, when the eye could choose its own most sensitive part, and the most favourable part of the spectrum was selected. If the observations were restricted to the centre of the eye the minimum illumination was increased about six times. This will be referred to as "the extinction value." The above illumination is for an object subtending an angle of $1° 30'$; the illumination depends on the angle, but there is no advantage in increasing this area beyond $4°$.

Paterson and Dudding have shown that for small sources it is the total flux which determines the visibility, and they regard $.02 \times 10^{-6}$ candles at one metre as the limit of visibility for direct vision. Their later results *seem to indicate* that the total flux is cumulative up to about 10′ of an arc; this result is in accordance with observations of Loeser extending to 8′ of an arc, but it is not altogether in agreement with those of Ricco and Charpentier who both consider that the effects are cumulative over the whole foveal area of about 50′. An explanation of this discrepancy, suggested by Abney's results, is that Paterson's measurements were not made for the absolute limit of visibility but for a match against a faint object (see below). Paterson and Dudding found that beyond the limits of 10′ the total flux, when the visibility is equal to that of their comparison object, varies directly as the linear dimensions of the source; *i.e.* the illumination multiplied by the linear dimensions of the source is constant. Piper shows that the last result holds good for the dark adapted periphery, when the areas are sufficiently large; later investigations indicate that his results do not apply for small areas. Abney's results show that there is no cumulative effect beyond 4°, so that the extinction values are as follows for the wave-length 530$\mu\mu$:

TABLE I

Size of object	Relative illumination for extinction
4° 11′	6.6
1° 3′	19.5
31′	63.

that is, the reduction beyond 1° 3′ is 1/3. The reduction from 31′ to 1° 3′ might be explained on the basis of reduction 50/31 x 63/31, that is, the effect is completely cumulative

up to 50′ and then varies as the linear dimensions, probably up to about 3°. Abney states that for smaller objects the results are well represented by a reduction of illumination of 10 for a reduction of area of 16.

It is interesting to compare the absolute values as given by Abney and Paterson. Abney's results give 96×10^{-6} candle metres as the minimum illumination and this is multiplied by 10 for an object of 31′ diameter.

Abney gives a most instructive comparison between the visibility of discs subtending angles of 1° 57′ and 10′ 46″ respectively. The discs are illuminated equally and the illumination increased till they are equally bright, and the illumination recorded. The illumination on the larger disc is then reduced to one half and the illuminations reduced together till they again appear equally bright. The table shows Abney's results, the ratio of the illuminations on the two discs being explicitly given; an additional column has been calculated, showing in each case the area on which the quantity of light, which is necessary to show the 10′ 46″ aperture, has been concentrated.

TABLE II

Ratio of illuminations	Log. illumination on smaller	Log. illumination on larger	Log. ratio of illumination of smaller to extinction value	Area over which "extinction light" is spread
1	3.66	3.66	2.58	33″ sq.
1/2	3.05	2.75	1.97	67″ sq.
1/4	2.54	1.94	1.46	120.3″ sq.
1/8	1.94	1.03	.86	240″ sq.
1/16	1.42	.22	.34	436″ sq.
1/32	1.16	— .34	.08	589″ sq.
1/52.5 (Extinction)	1.08	— .64	——	——

It will be noticed that the two areas show the same brightness for the same illumination, if *at least the extinction quantity of light* be concentrated on the unit area repre-

sented by one cone. The illumination for which the two areas are equally bright is about 2 metre candles. When the illumination is reduced to 1/4 this quantity of light is spread over an area four times as large in the smaller and eight times in the larger.

Extinction of Colour

When the illumination is reduced the colour will disappear before the extinction of the light. Abney's results on the extinction of colour show that: (1) the illumination at which colour disappears has a minimum value of about .0025 metre candle for wave-lengths about 470$\mu\mu$, the size of the patch of light being about 1° 30′; another observer gives .0012; (2) the illumination at which the loss of colour takes place may be increased ten times if the linear dimensions of the object be increased eight times. The latter result suggests that, when an allowance is made for the effect of pupil changes, the illumination varies inversely as the linear dimensions. Using Abney's values and extrapolating for smaller apertures, the illumination necessary for the recognition of colour on a patch of 1/2′ square would be approximately 2 metre candles, being approximately the same as for the recognition of the actual brightness of an object.

Paterson's results suggest that for the recognition of light the illumination multiplied by the area is constant up to a definite angular size and that beyond this size it is the linear dimension multiplied by the illumination that remains constant. We have seen that the boundary value of 10′ given by Paterson is probably determined by the actual quantity of light used, and that by still further reducing the comparison source the value would probably be extended to the foveal area.

The general conclusion is that the eye is capable of adding up the effects in various ways; (1) For *the recognition of true intrinsic brightness* of the object, the quantity of

light necessary for recognition of light must be concentrated on the area of a single cone. (2) For the *recognition of colour* the effect of increased area is that the illumination multiplied by the linear dimensions is constant; while the illumination so calculated for the area of a single cone is that necessary for the recognition of the intrinsic brightness. (3) When necessary for the *recognition of light* the total quantity of light may be added up for areas not greater than about 50′ square, and the quantity so received is about $.02 \times 10^{-6}$ candles at 1 metre. When the area exceeds 50′ square the total quantity of light necessary for recognition varies as the linear dimensions of the object up to about 3°.

The results show that, after making the correction indicated above for pupil size, the illumination varies inversely as the linear dimensions to the power 3/2. No satisfactory explanation of this result can be given, and in view of the other observations it seems probable that some special conditions of adaptation or illumination have led to unusual results; this view is confirmed by the fact that Abney found the extinction values to be independent of the linear dimensions in one direction.

The idea that the area over which the effects are cumulative depends on the greatest illumination in the field receives considerable support from Abney's observations on the effect of general illumination on extinction values. Abney has measured the effect of the general illumination on the quantity of light required for recognition of light; this effect is due to two causes, *viz.:* the reduction of the pupil size and the reduction of the area over which the light received is cumulative.

When the general illumination in the field was increased, the illumination required to render visible a disc of 1° diameter was determined. With a general illumination of two candle metres the value was found to be roughly 100 times the minimum value for the case where there was no general illumination in the field. For the above illumination

the flux corresponding to .02 x 10^{-6} candles at 1 metre is received on an area of about 40″ square, and we may assume that the eye adapts itself so that the flux is cumulative over this area, but that above this area the illumination required for visibility varies as the linear dimensions of the object. On this assumption the illumination for visibility would be 50′/40″ times the minimum; *i.e.* about 75 times the minimum, or making allowances for the change of pupil size approximately 120 times the minimum, which is in sufficiently good agreement with the observations.

When comparisons are made with other values of the general illumination, in the part of the spectrum to which the eye is most sensitive, it will be found that quite roughly the extinction value is doubled when the general illumination is multiplied by four. These results do not hold even approximately towards the ends of the spectrum, the extinction value increasing more rapidly towards the blue and less rapidly towards the red. The behaviour at the red end of the spectrum is anomalous throughout, the quantities of light required for the recognition of colour of light differing much less than at other parts of the spectrum. The behaviour is such as to suggest that when the red sensation is stimulated there is also a sensation of light, but that the effects are cumulative only in the same way as the sensation of colour, *i.e.* the effects vary more nearly as the linear dimensions of the object.

In general the flux may be taken to be cumulative for the area on which the unit quantity (.02 x 10^{-6} candles at 1 metre) is spread and then is cumulative in proportion to the linear dimensions instead of the area.

The minimum illumination of about 96 x 10^{-6} metre candle corresponds to a very small amount of energy on each element of the retina.

The energy per square minute may be calculated to be 7 x 10^{-12} ergs per sec., if we assume a pupil size of 8 mm. and use Drysdale's value for the mechanical equivalent of mono-

chromatic light. For dark adapted eyes the effect of a given light intensity increases with the duration of exposure up to 1/5 sec., and for values near extinction it is probable that this time increases. Taking 1/5 sec., the energy per square minute is 1.4×10^{-12} ergs, which is comparable with the "quantum" of energy for a wave-length $.5\mu$, *viz.* 3.6×10^{-12} ergs. Thus the quantum of energy must be received on an area which does not exceed two or three square minutes. An experimental determination of the time required for recognition of brightness with the least illumination for central vision would be useful as it would give the area on which the quantum of energy must be received to give an impression of light.

Thus the visibility is limited by the necessity of concentrating this quantity of light on a sufficiently small element of the retina; it is also limited by the necessity of transmitting the record to the brain and this requires the reception of light corresponding to $.02 \times 10^{-6}$ candles at 1 metre. This is equivalent to about 8000 times the minimum quantity of energy per square minute and seems to be required for the transmission of the record.

The effects described for the eye would occur if the various receiving circuits were arranged to collect the energy in the same way as a set of receivers in series, but as soon as there is recognition of light the receivers are subdivided in a manner depending on the greatest illumination in the field. This subdivision continues as long as the necessary quantity of light is received to transmit the message, each group of receivers collecting its own energy and "sending" by its own circuit, the message being recorded by the energy sent by all the groups. When the receiving group is reduced to one element, perception of colour is possible, and when the message can be sent by *one element alone*, recognition of intrinsic brightness independently of the area becomes possible.

Visual Acuity and Brightness

It is common experience that visual acuity depends on the illumination. Since a certain amount of light is necessary to produce the sensation of light, it seems obvious that detail cannot be recognized unless each element of the detail sends to the eye sufficient light for its recognition. Drualt has made a series of observations recorded in Tscherning's *Physiologic Optics*. The results are given in the following table; the first two columns are quoted from Tscherning and the remainder have been calculated by the present author.

TABLE III

Illumination I	Acuity A	I/A^2	Candles per unit square of chart	Corrected for pupil size
Metre candles				
0.016	15/200=0.075	2.9	——	——
0.020	15/100=0.15	.89	2.5 10^{-8}	——
0.028	15/70=0.21	.62	1.74 10^{-8}	1.74 10^{-8}
0.047	15/50=0.30	.52	1.45 10^{-8}	1.30 10^{-8}
0.12	15/40=0.37	.85	2.35 10^{-8}	1.76 10^{-8}
0.25	15/30=0.50	1.00	2.8 10^{-8}	1.82 10^{-8}
0.67	15/20=0.75	1.18	3.3 10^{-8}	1.75 10^{-8}
1.50	15/15=1.00	1.50	4.2 10^{-8}	1.89 10^{-8}
16.7	15/12=1.25	——	——	——
5400	15/10=1.50	——	——	——

It will be noticed that apart from the one value these results show remarkable agreement with Paterson's value for the minimum source of light; that they are rather lower is partly due to the fact that the values are reduced to a pupil size corresponding to a lower degree of illumination. It will be noticed that the illumination must be more rapidly increased beyond 5′ of arc; this is partly due to the fact that the recognition is of Snellen's chart, in which the length of the whole letter is five times the unit length in the chart.

Contrast in Illumination

In order that contrast shall be detected it is necessary that the difference in illumination be at least 0.5 per cent. of the actual illumination. But if this illumination falls below a certain value the fraction increases. This is due to the necessity for a certain minimum quantity of light to produce any effect. The effect of any additional illumination will be cumulative over a considerable area, but *only as the linear dimensions above the area for which the normal illumination is effective.* Thus, if the actual illumination be such as to define minutes, the additional light will be cumulative over an area of about 180°, so that the additional fraction of the illumination which can be detected is about 1/180; as the illumination decreases below this value the area which is defined will vary inversely as the illumination, and the ratio will vary approximately as $I^{-1/2}$. Thus at .25 metre candles the fraction would be about 1.1 per cent. at .12 metre candles about 1.6 per cent. and at .03 about 3.2 per cent. These values are intermediate between those given by Broca and Dow. The effect of increase of the pupil size with the decreased illumination should make the falling off somewhat slower.

(Abstracted from *Transactions of the Optical Society*, Vol. XX, pages 297-314 1919.)

Visual Fatigue

Edward Jackson, M. D.

[This paper by Dr. Jackson deals in such a straight-forward and clear manner with a topic of much importance to those interested in many of the practical, everyday problems of physiologic optics, that we are pleased to present it *in toto* in this *Journal.* ED.]

THE supposed basis of fatigue is exhaustion of prepared cell nutriment, and accumulation of waste products of cell activity; with a probability that the latter process brings a decrease of activity, before the stored nourishment in the cell is nearly exhausted. As regards muscle

cells it seems fairly well established that the accumulation of acids, especially carbonic and lactic, is closely associated with diminished responses to stimuli.

The nature of the products accumulated in the nerve cell is not so clear. Crile and Lower found in shock or exhaustion, visible changes under the microscope in nerve and gland cells, in the brain, suprarenals and liver.

The symptoms of general fatigue, slow and feeble motor reactions, blunted perceptions, disagreeable sensations of general weariness, desire to sleep, indisposition to exertion or activity, either muscular or mental, which are familiar to all persons, may be attributable to such changes. But we cannot regard them as necessarily following fatigue of a limited neuro-muscular tract, such as is directly concerned in the act of vision, although fatigue of such a limited tract may contribute to a general fatigue.

Visual fatigue may contribute to general weariness, but can hardly cause it alone. It may be essentially similar to general exhaustion in the histologic changes on which it rests; but there is a wide gap between our knowledge of chemic and histologic changes; and the clinical manifestations of fatigue that confront us as a practical problem. Even of weariness produced by exertion of the large muscles, as in walking, Barker says, "Whether this is due to centripetal impulses arising in the muscles themselves, or to a change in the nerve centers in the central cortex is not certain."

The number of points at which fatigue might occur so as to lower activity or cause sensations of which we are conscious, are thus enumerated by Herrick, who bases them on the summary of Stiles: "(1) Fatigue of muscle fibres; (2) fatigue of the junction of the motor nerve with the muscle fibre at the motor end-plate; (3) fatigue of the nerve-fibres; (4) fatigue of the motor nerve cells; (5) fatigue of the synapses between the nerve cells; (6) fatigue of the sense organs and afferent apparatus; (7) fatigue of the centers of voluntary control."

Physiologic experiment shows that the nerve fibres are capable of conducting impulses after the neuro-muscular apparatus has become exhausted and fails to respond to stimulus; and that muscle fibres cease to respond to impulses coming through the nerve trunk, and yet contract well under direct stimulation. This shows that neither the muscles nor the nerve fibre is exhausted.

Stiles thinks the junction of nerve and muscle is especially likely to give out under continued stimulation. He says: "One is tempted to draw a comparison between the end-plate and the safety fuse such as is used in connection with an electric fixture. The fuse is intended to be destroyed under conditions which might otherwise threaten damage to more valuable portions of the system. It is readily renewed. So we may think of the end-plate as something easily impaired by us, but also easy to repair. It is better that wear and tear should fall upon this structure than upon the more highly organized protoplasm of nerve cells or muscle fibres."

Next in importance as a point especially liable to manifest fatigue, are the synapses through which stimulation of motor nerve cells is effected. It is easily conceivable that here a break in the circuit may occur; and that one set of these being out of use, another set can be brought into service under forced effort, made to continue the action. What changes mark physiologic fatigue in the body of the nerve cell, or to what extent it is the seat of fatigue we can only guess. The important point to be here impressed is the large number of structures, any one of which might present essential alterations of fatigue; and our lack of definite knowledge of its location.

Overuse of the large muscles produces symptoms directly referable to the seat of increased activity, including pain, that arises into consciousness and causes inhibitory impulses that tend to check the use of the muscle. There is pain produced by pressure on the muscle or its tendons; and this

soreness or tenderness seems identical with that produced by simple bruise of the part. One symptom of muscle fatigue is local pain due to congestion, but such pain is rarely complained of about the eye. Lippincott reported localized congestion over the insertion of the internal rectus in three cases. I have seen something of the kind, but very rarely. Patients complain of general soreness "back of the eye," and show decided wincing when the eyeball is pressed back into the orbit. This might indicate soreness in the extra-ocular muscles deep in the orbit and particularly in their tendons of origin and points of attachment.

But it is characteristic of muscle soreness from overuse that it is a temporary symptom. One starts to play tennis or to swim at the beginning of the season, or takes a long walk; and after the one day of rather prolonged exercise his muscles feel sore. But if he continues such use of his muscles daily, the soreness will reach its maximum in a very few days; and in two or more weeks will have disappeared entirely. If the beginning of the unaccustomed exercise is quite gradual, and the period gradually lengthened, or when the exercise is habitual no such symptoms will arise. We may suppose that in the case of the eye, habit or more gradual change in the way the eyes are used, eliminates this symptom of fatigue.

Perhaps the most constant and general symptom of visual fatigue is a sensation of dryness, roughness, burning, smarting or feeling of a foreign body in the eye. Children are told the "sandman" is after them and they must go to sleep. These sensations bring to us a fair proportion of patients. Ferree and Rand have depended largely on the discomfort produced in their experiments on the production of fatigue by various colors and forms of illumination. Some individuals and the members of some families are especially liable to it; but the mass of eye workers can accept such sensations as a fair notice that it is time to stop work. It seems closely connected with hyperemia of the conjunctiva,

and might be an expression of weariness in certain parts of the visual apparatus through lowered vasomotor tone. Failure to heed the warning it gives furnishes cases of chronic conjunctival hyperemia and inflammation, or makes such disease resistant to treatment. Attacks of conjunctivitis due to visual fatigue are common among presbyopes who are deferring the use of the needed help for accommodation.

In this respect we may trace one more analogy between eye and brain. As Weir Mitchell puts it: "It is only after very long misuse that the brain begins to have means of saying, 'I have done enough'; and at this stage the warning comes too often in the shape of some one of the many symptoms which indicate that the organ is already talking with the tongue of disease."

Still more does the eye speak with the "tongue of disease" when it expresses fatigue by eyeache or headache. In the mass of cases these symptoms express the establishment of a pathologic reaction to stimulus; rather than an expression of temporary weariness, that a period of rest will presently remove. Whether in either brain-work or eye-work the aching originates in centripetal impulses, or in exhausted central cells, we do not know. Local influences like pressure on the eye or head may modify pain or relieve it; but this does not throw light on the locality of the morbid action, as it does in the case of the soreness of muscles and tendons.

The close association of eye and brain symptoms may arise from the fact that the brain, or certain parts of it, are using the eye to effect certain purposes. As H. C. Wood says, "The thinking machine—the brain—works with certain tools. It is clear that, if these tools or instruments be dull or out of order, an enormous loss of power must occur in using them. The most important of these tools of the brain are the special senses. It is of the first importance to have the organs of the special senses in good order." "This process of eye-strain and brain-strain may go on unrecognized for years, until at last the individual is arrested by the giving

out of the brain, or by the retinal irritations becoming so severe that vision is no longer endurable." Again the lesson is not recognized until proclaimed by the "tongue of disease."

Whether the aching of some myopic eyes belongs with the eyeaches and headaches of hyperopia; or whether it should be classed with the soreness of the overworked muscle and congested tendon is somewhat uncertain. Perhaps both kinds of aching contribute to these exceptional cases.

Fatigue of the retina and visual centers is of more importance than all other forms of fatigue connected with vision. We cannot discriminate between that which belongs to the retina and that which belongs to the intracranial neurons of the visual apparatus. Nevertheless we have some definite knowledge about this kind of visual fatigue. In the first place it is attended with lowered visual acuity. This dropping of visual acuity begins very soon after the eyes are brought into use; and it is a phenomenon common to all the eyes we test. We find habitually that a patient with the eye properly focused gets his best vision on first looking at the test card, after a slight period of rest. If he does not utilize it and attempts to decide on doubtful letters by steadily looking at them, he makes more and more mistakes. Often the patient almost says the right letter or quite utters it, and then immediately changes his mind and says something else.

This original maximum of retinal-central resolving power very quickly drops to a noticeable extent, and then decreases much more slowly, soon reaching a level where little change may be noted for a long time. Its course is modified by age, by previous exposure to light and by disease. It is closely associated with adaptation—indeed is a phase of the same process. In many patients decidedly better vision can be obtained, even by the best daylight, after they have been kept several minutes in the dark room, or in a dimly lighted reception room. This is particularly the case with patients who have retinal deterioration with high myopia or other

intraocular disease. This latter fact points strongly to the retinal nature of this form of fatigue. But it is not established definitely enough, or sufficiently supported by experiment or special observation to settle the point completely. It may be agreed that this manifestation of fatigue is partly or sometimes retinal, but it is not established that it is always or wholly retinal.

Closely related to the matter of lowered visual acuity is the fatigue significance of after-images. These have received some attention in the literature, although not as much as their practical importance warrants. In all our visual and especially our accurate color testing, and testing of night vision, more attention must be paid to the matter of adaptation, the elimination of after-images of all objects previously looked at.

Another point about retinal-central fatigue is that it is increased by great difference in the intensity of stimulus to which adjoining parts of the retina are subjected. This disagreeable effect of looking at a bright light against a dark background is familiar to all of us, and is a common cause of complaint by patients. Clearly such contrasts are fatiguing, and must be reduced to a minimum compatible with the required use of the eyes. This phase of fatigue is of all the greater importance, because the resolving power of the eye depends on sharpness of contrast.

Our reading of black letters on a white background is an instance of this application of resolving power. The sharper the contrast the farther away the letters can be recognized; but the greater the fatigue if the reading is continued. Here as elsewhere a compromise, or medium adjustment of contrast must be sought which will give the optimum of efficiency for the eyes. Brightness of illumination of the page, color of the background and general illumination of the room in which reading is to be done, all have to be considered. There is need for systematic observation with regard to all these factors, in general; and also with reference to the particular patient to be considered.

Finally we have to consider fatigue of coördination; for the visual act is extremely complex—is only complete by the coördination of many separate physiologic processes. This kind of fatigue arises somewhere in the central nervous system. We do not know exactly where, but the synapses of the neurons may be assumed as a probable location. The stimuli for each of the six muscles of each eye must be coördinated with each other, and with the sensory impressions on the retina, in order that the eye shall be turned in the desired direction. The stimuli to the muscles of the two eyes have to be coördinated for binocular vision. The sensory impressions have to be coördinated with each other and with visual memories. This makes an extremely extensive and elaborate system of coördination, beside which the most complicated telephone switchboard must seem simplicity itself.

Probably the usually recognized signs of eye weariness are fatigue of coördination. When paresis of one or more ocular muscles arises, the strain to coördinate under such a handicap quickly causes headache, vertigo, nausea, abandonment of binocular vision. The lack of correspondence of the images obtained through new glasses, with the visual memories of the patient, causes the distortion of perspective and judgment; and the ensuing annoyance of fatigue, that patients complain of so bitterly when oblique cylinders or lenses of unequal strength are prescribed to correct their ametropia. Even the fatigue of good eyes for ordinary near work must be largely a matter of fatigue of coördination. In my own case, the effort of keeping up binocular fixation and avoiding diplopia, with the necessary accommodation for reading, when getting drowsy, comes nearer to the effort of completing a long walk or mountain climb, than anything else my eyes have to do.

Some realization of the importance of this fatigue of coördination should give a better balanced judgment as to the adoption of therapeutic measures for the relief of eye-

strain. The problems of visual fatigue are important, timely, practical problems, to which the recent advances of our knowledge of physiology, with carefully devised methods of experiment can be applied with great prospect of achieving results of value.

Some analysis of the different forms of such fatigue, an attempt to localize the essential change that gives rise to fatigue, and a recognition of the extremely important part that efforts of coördination play in producing fatigue, ought to be useful in giving us a better conception of a condition that passes easily from physiologic to pathologic significance.

It should be borne in mind that normal visual fatigue rarely rises into consciousness. Only when the organism in response to long continued or repeated excessive fatigue has developed a method of translating this into discomfort or pain, does it develop into symptoms that bring patients to us for relief.

(From the *American Journal of Ophthalmology*, Vol. 4, p. 119-122, 1921.)

Some Optical Imperfections of the Eye and Some of Their Uses

Henry Sewall, M. D., Sc. D.

AFTER calling attention to the fact that the greatest master builder of the science of physiological optics, von Helmholtz, declared, in effect, that should an instrument maker send him a camera as optically defective as the human eye he would reject the apparatus with a stinging rebuke, the writer goes on to emphasize the fact that the vast preponderance of the visual world is, at any moment, represented in consciousness by ill-defined and physically inaccurate images. Hence it would be an insolent presumption to assume their uselessness. Rather should they be regarded as the necessary background through which the distinct foveal image acquires a meaning it could not achieve alone. Sen-

sations from the periphery of the retina with all their obscurity of form and texture, must, from the very preponderance of the nerve mechanism involved, form an essential fund of visual knowledge.

The writer describes the following experiment: "If any one looks at the page of a book or at a piece of plain white paper which is illuminated only by the light of an ordinary reading lamp placed on one side, an interesting series of color phenomena may be demonstrated without the aid of any objective color. When the light is on the right side and the partly separated fingers of the left hand are placed over the face so that different portions of the paper surface are seen by each eye, any one may observe that the sheet appears to have a greenish tint where seen by the right eye, while the color approaches a more or less decided red or orange in those parts of the surface whose light enters the left eye only. It is easy to place the fingers so that only narrow streaks of the white paper can be seen by the right eye while the light from the rest of the surface all enters the left eye. In this case the visual ground is colored red with green bands distributed through it."

"The same facts may readily be demonstrated by holding an ordinary visiting card between the eyes so that but half of the page looked at can be seen by each organ; that part towards the source of light appears green and the other red.

"Quite the same contrasting color sensations may be produced by the use of ordinary sunlight whenever it falls directly upon the side of the head; a white surface appears greenish to the illuminated eye and pale red to the other."

These color phenomena depend upon the passage of light through the sclerotic and choroid coats. The color may be accentuated by concentrating the light by means of a lens upon the sclerotic of one eye.

Brücke in 1840 investigated this subject thoroughly, for he first showed that the color sensations were due to light transmitted through the two outer coats of the eye and not

by way of the pupil. The light so passing cannot form definite images but is diffused over the retina. This light, having first penetrated membranes rich in blood, is not white but rather red or rosy in tint. This red light fatigues the red sensitive mechanism of the retina, so that light entering by the pupil excites with preponderance the resting "green elements," hence the reason why the illustrated eye has the greenish tinge according to the familiar law of simultaneous contrast. To the eye not illuminated by oblique light the white surface takes on a tint complementary to the green as a result of subjective contrast.

Further, we should expect that objective greens and colors near the spectral green should appear brighter and more saturated when looked at with the eye which has been obliquely illuminated, while the red and orange tints should lose in brightness and purity, and *vice versa* with the eye lacking the oblique illumination. The following substantiates this expectation: On a clear night the stars and planets may be made to take on a faint color when an artificial light is held by the side of the head.

"When I look at a star while holding a light in the right hand and pass an opaque card alternately before the two eyes, the star appears greenish to the right but yellowish or orange to the left eye."

"It seems not an undue straining of the facts that have already been mentioned to presume that the exhilarating effect of objective green is partly if not solely due to the light which is colored red by penetrating the side walls of the eyes, and which, by gently stimulating the red elements of the retina, keeps up a constant background of contrast for the green light which enters the pupils, thus insuring its continual freshness. In this sense the indirect light may be said to keep the retina in tone for those colors with which nature commonly presents us.

"On a bright day in May I stood looking out of a window upon a grass-covered field. The herbage was brilliantly

green in hue with a decided tinge of yellow, and aroused in the beholder an indescribable sense of well-being. A common pasteboard mask or "false face," such as children use in play, but blackened inside and with the eyeholes reduced nearly to the size of the pupils, was now placed over the face so that scarcely any light could enter the eye except through the pupils. The landscape appeared very different under these conditions. The green light of the grass lost its brilliancy and gradually faded; the yellow sensation became stronger, and the general impression produced was that of a field parched by intense heat. A group of deeply green cedar trees seemed to have a rusty hue and the agreeable condition gave way to a sense of depression."

"Various facts indicate that it is the substance in the retina sensitive to green light that is specially differentiated to give visual impressions their distinctness. It follows naturally that any influence which exalts the irritability of the green visual substance should raise the acuteness of vision above the normal; and we have already seen that light penetrating the side walls of the eye may be regarded as having this effect of stimulating the green retinal element to an excessive and continuous irritability. Whatever the value of these theoretic considerations, experiment shows that acuteness of vision is decidedly greater when light is allowed to impinge upon the side of the eyes than when it is permitted to enter the pupils only."

The conclusion is recorded that, "smaller angles can be perceived and parallel lines distinguished when nearer together if light fall upon the eyes from the side than when such side light is excluded."

(Abstracted from the *American Journal of Ophthalmology*, Vol. 3, p. 865, 1920.)

The American Journal *of* Physiological Optics

The Lateral Adaptability of the Extrinsic Ocular Muscles in Ametropia

Charles F. Prentice, M. E.

Author of a Treatise on Ophthalmic Lenses (1886), Dioptric Formulae for Combined Cylindrical Lenses (1888), The Metric System of Numbering and Measuring Prisms (the Prism-dioptry) (1890), The Iris as Diaphragm and Photostat (1895), The Typoscope (1897), The Chiasmal Image (1914), Vertex Refraction in its True Aspect (1915), The Fundamentals of Achromatism (1915), Ophthalmic Lenses and Prisms (1917) and other optical papers. President of the New York State Board of Optometry (1908-1918), Special Lecturer on Theoretic Optometry, Columbia University, New York (1910-1918) and Collaborator on the American Encyclopedia of Ophthalmology (1914-1921).

[*Author's Note:* In an effort to emphasize certain salient points in the following discussion and to insure unequivocal interpretation of the author's contention, restriction has not been placed upon repetitions that may be apparent in the text. In the interest of greater clearness, the interpupillary distances had to be exaggerated in the diagrams. The author will also cheerfully answer personal correspondence pertaining to this unusual discourse, if addressed in care of the *Editor.*]

SO much has already appeared in print respecting so-called imbalances of the extrinsic ocular muscles that the author has long and seriously hesitated to express still another opinion, though it is one upon which he has, since 1893, strictly based his own practice, as a purely physical eye specialist.

For five years prior to this date he too had grotesquely prescribed prisms for lateral deviations of the visual lines, whenever such so-called muscular anomalies seemed to be associated with ametropia. Besides, the author had become familiar with the "phorias," through having read Dr.

George T. Stevens' work on *Functional Nervous Diseases*, published in 1888. Some recent correspondence upon this subject with Dr. Thomas Hall Shastid, of Superior, Wis., has, however, encouraged publicity being given to the author's views, at the risk, of course, of fully expected criticism that should, however, be preceded by careful study of Landolt's standard work: *The Refraction and Accommodation of the Eye*, Edinburgh, 1886, which is now regrettably out of print, though generally accessible in the larger medical libraries. Moreover, the excuse for this final publicity is the belief that it may lead others to follow a newly blazed trail that will surely circumvent some of the pitfalls incident to illy conceived prescriptions for ophthalmic lenses.

As already intimated, the author has himself had such experiences, until it was discovered that most persons for whom lateral prisms had been prescribed did not usually revisit him; whereas, those patients who had been given *vertical* prisms generally did return for subsequent examinations, and commonly expressed great satisfaction respecting the comfort they had derived from them. In fact, in many instances, where both vertical and lateral prismatic power had been prescribed for the same patient, it was discovered that subsequent removal of the lateral prisms afforded still more comfortable vision, showing that the comfort derived was actually due to the vertical prismatic power inherent in the compound lenses; in spite of the fact that the removed lateral prismatic power exceeded the hyperphoria, and which was evidently all that required correction, so far as prisms were concerned. Moreover, this is now actually emphasized by Maddox, who, in the January issue of this *Journal* says: "If lateral deviations are complicated by hyperphoria, correct the vertical deviation first and the lateral will very likely correct itself."

In an effort to account for this experience and to avoid similar mistakes during subsequent practice, it occurred to the author that, while nature does not, through the force of

will or effort provide for effective self-adjustment of vertical deviations between the visual lines, it does, nevertheless, amply provide compensatory lateral adjustments of the extrinsic ocular muscles within certain limits; that is to say, the lateral swings, AB and A_1 B_1, of the visual lines, Fig. 1, take place between the maxima of positive and negative convergence, and in such a manner as to adapt themselves to the ametropia that may exist.

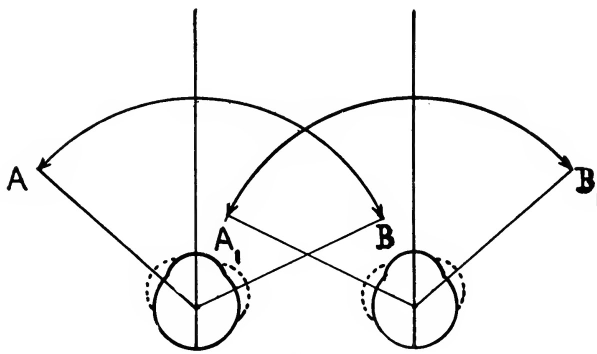


Fig. 1

For convenience this so-called amplitude of convergence shall be recognized in this article as *the range of lateral adaptability of the extrinsic ocular muscles.*[1] It will be first shown that this lateral adaptability differs in each individual hyperope, and according to the amount of accommodation he is forced to exercise during maintenance of a fixed convergence for distance; thus, through force of habit, establishing his own particular kind of equilibrium between convergence and accommodation.

The usual tests for adduction and abduction in themselves prove that the powers of convergence and divergence may

[1] Landolt, on page 210, clearly implies the existence of this adaptability in his treatment of the Relative Amplitudes of Accommodation and Convergence.

be most seriously interfered with, or taxed, before diplopia is produced by means of prisms of augmentative power and, therefore, also proves the existence of a wide range of adaptability of the lateral muscles that may be called upon to provide the required coördination between a normal angle of convergence and any enforced accommodation that may be necessary to secure the best attainable vision for distance. In other words, this lays the foundation for the possibility of the eyes being in any required state of accommodation for distance during proper convergence to six meters.

All of our physical functions are developed through need of their use. Even in early infancy we have to actually learn to see,[2] and it is *then* that we acquire the habit of associating accommodation with convergence, and in such proportions to each other as to secure the best achievable vision. So far as vision broadly speaking is concerned, the first binocular impulse is to see singly, notwithstanding how poorly defined the object viewed may appear to be, since a blurred single image is infinitely easier of mental conception than distinct double images could ever be. The second necessary impulse is to so accommodate as to produce the most distinct single image that is procurable under the circumstance of an existing optical defect, usually hyperopia and its affiliations, since in emmetropia and myopia accommodation would be detrimental to distance vision. In fact, as in infancy hyperopia is the rule and may later develop into emmetropia and subsequently into myopia, it is very apparent that, from the very beginning, every individual will develop his own peculiar adjustment of the proportions of convergence and accommodation that shall be associated in the attainment of vision. Hence, these proportions will depend upon the optical status prevailing in each case as time goes on, so that children, for obvious reasons, should be examined annually. In other words, the

[2] Inverted Retinal Images, Charles F. Prentice, *Ophthalmic Record*, January, 1916.

proportions of convergence and accommodation constitute an acquired relativity in every individual case of ametropia.

The theoretic ideal relationship between convergence and accommodation is, therefore, if found, of extremely rare occurrence, and yet it is what most ophthalmic practitioners too ardently seek to attain through prismatic amplification, when lenses are to be prescribed. In the author's opinion, this is generally a mistake. From a strictly *theoretic* point

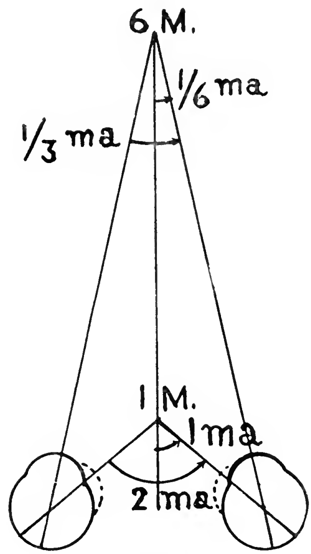


Fig. 2

of view, orthoscopic vision is secured when convergence and accommodation are so related to each other that each dioptry of monocular accommodation is associated with one meter angle of convergence. It is also an axiom that rays of light proceeding from a distance of 6 meters are virtually considered to be parallel. For this reason the accommodation of the normal eye for distance is said to be nil.

Practically, however, in emmetropia, Fig. 2, the ac-

commodation for a six meter distance is 1/6 of a dioptry, and the convergence for the same distance is 1/6 of a meter angle for each eye; or binocularly 2 × 1/6 = 1/3 *m a* is the total deviation between the two visual lines. Similarly, at the one meter distance, the deviation between both visual lines is 2 *m a*, while the accommodation is 1 dioptry for each eye, and so on. Unfortunately, persons with eyes in which these ideal conditions exist are rarely, if ever, met with in the practitioner's office.

However, the ever-present patient is the hyperope, who, merely for convenience, we shall consider to have a facul-

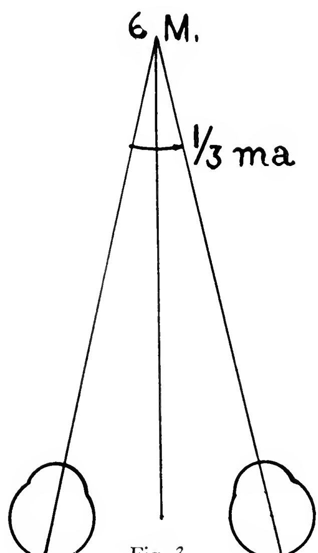


Fig. 3

tative hyperopia of 1 dioptry. In being directed to look at letters at 6 meters, he must exercise the *primary* impulse to see the chart as a single object and, therefore, like the emmetrope, uses 1/6 *m a* of convergence for each eye, or 1/3 *m a* between both visual lines (*vide* Fig. 3). Owing to his

facultative hyperopia, he uses 1 dioptry of accommodation instead of 1/6 of a dioptry to see the letters at 6 meters, so that his accommodation is 5/6 of a dioptry in excess of what it should *theoretically* be for his convergence to 6 meters. On the other hand, his enforced use of 1 dioptry of accommodation should *theoretically* be associated with 2 *m a* of convergence between the two visual lines instead of the 1/3 *m a* actually being used. The theoretic ideal harmony between convergence and accommodation for this hyperope is evidently upset, and yet with a normal amplitude of accommodation he might live to be 37 years old without seeking the aid of glasses, especially if he is not clerically employed. Such fulfillment would, of course, be very rare.

What should actually occur, when a comparison is made with the *theoretic* ideal coördination of muscular adjustments, is this: His use of 1 dioptry of accommodation should be associated with 2 *m a* of deviation between the visual lines, Fig. 4, but of which he is actually using only 1/3 *m a*, so that he has to suppress at least the difference between 2 *m a* and 1/3 *m a*, or 1 2/3 *m a* of convergence between the visual lines, if he is to see the object of fixation singly at a distance of 6 meters. [3] This, however, can only be accomplished through his having invaded the range of his lateral muscular adaptability, which means that his internal recti muscles must have given way to their antagonists, the external recti muscles. Otherwise the Maddox rod-test would show a pronounced esotropia, owing to a crossing of the visual lines to include at least the 1 2/3 *m a* of binocular convergence and that would have made single vision impossible, through homonymous diplopia; also illustrated in Fig. 62 and described under Ophthalmic Lenses and Prisms, *American Encyclopedia of Ophthalmology.*

In the *Archives of Ophthalmology*, January, 1890, the writer originated the rule: "Read the patient's inter-

[3] Landolt, on page 199, states a similar example, though for a different value of hyperopia.

pupillary distance in centimeters, when one half of it will indicate the prism-dioptries required to substitute one meter-angle for each eye."

Hence, in the case under consideration, for an inter-pupillary distance of, say, 60 millimeters, 3 centimeters would give 3^{Δ} as the value of 1 *m a*, so that with inability to suppress the aforesaid 1 2/3 *m a* there should be $3 \times 1\ 2/3 = 5^{\Delta}$ of *esotropia;* and esotropia it would be, on account of the visual lines crossing to produce homonymous diplopia and not single vision. But, this esotropia would not be dis-

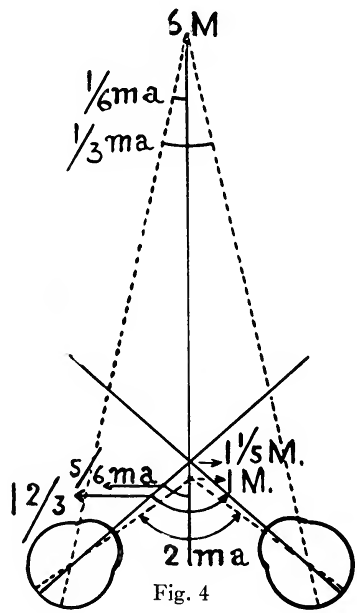


Fig. 4

covered in this case, because the lateral muscles have been, presumably for a long period, subjected to selective training to maintain single vision under conditions not in harmony with the ideal coördination of the extrinsic and intrinsic ocular muscles. The actual condition can, therefore, only

be considered a theoretic disequilibrium between convergence and accommodation, when the conception of their ideal association [4] is used as a basis of comparison, and which can not, or should not be done in *practice*, since only an esophoria of from 1^{Δ} to 3^{Δ} would, in this case, be manifest, and then only on account of the Maddox rod discouraging the enforced fusion.

In any event, such manifestations of esophoria are only to be construed as *symptoms* that are apt to follow long continued efforts to maintain at least a semblance of harmony between convergence and accommodation for distance. If such is the case, then, of course, it is of primary importance to accurately determine and prescribe for the hyperopia, before attempting to correct any lateral muscle-imbalances that may at the time seem manifest. It has been the author's experience that such apparent imbalances soon disappear after the proper glasses have been worn sufficiently long for a readjustment of the muscles to have taken place within the range of their ever susceptible lateral adaptability. It is, of course, to be expected that a long standing unavoidably enforced habit will eventually succumb to nature's more easily accomplished readjustment of convergence and accommodation under the benign influence of lenses that perfectly correct the hyperopia, and which relieve the necessity for the struggle to maintain comfortable vision.

In general, much depends upon the lateral range, or amplitude, of adaptability and the amount of accommodation that is enforced to correct, or partially correct, the hyperopia, and it should be evident that inclination to exophoria will be increased when the adductive power is low, or the hyperopia is more pronounced. But, in any event, prisms of from 1^{Δ} to 3^{Δ} can supplant only a very inadequate proportion of the lacking convergence in such

[4] Landolt, on page 198, says: "Accommodation is, therefore, not so absolutely allied with convergence as certain authors would have us suppose."

cases, and prisms of higher power are associated with aberrative phenomena, internal reflections and astigmatism, which are infinitely more detrimental to vision than the defects which it is intended should be corrected by them.

It should not be lost sight of that strong prisms only transmit light that is free from astigmatism when light reaches them from infinity. When light proceeds from short finite distances, such as the reading distance, the incident divergent pencils, C, Fig. 5, of light are refracted as astigmatic pencils that are both undesirable and incapable of advantageous utilization. (Also described under Ophthalmic Lenses and Prisms in the *American Encyclopedia of*

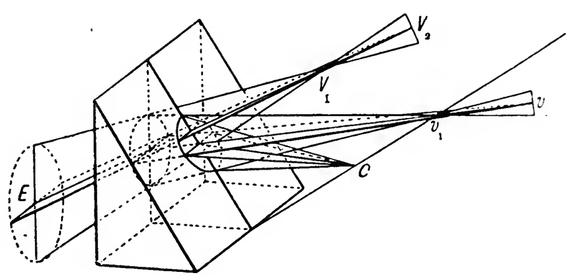


Fig. 5

Ophthalmology.) However, it is conceded that great relief may be secured through the use of vertical prisms of moderate power, and which, therefore, are advisedly prescribed in cases of hyperphoria, being the only use the author has made of them.

It is the author's opinion, based upon an experience gained during forty years practice that, the use of prisms, for the attempted correction of lateral muscle imbalances, only retards normal recovery. It has, therefore, been his policy, since 1895, to remove lateral prisms previously prescribed even by others, though it was at times necessary at

first to reduce their powers before it was possible to entirely discard them. This proves that the eyes had merely adapted themselves to the prisms while they were being worn, as otherwise they would have been previously discarded by the patient. This is another proof of the infractions that may be imposed upon the lateral adaptability of the muscles. Moreover, if such adaptability did not exist, some persons would not be able to wear even correct spectacles for distance, since the use of lenses imposes a tax on the extrinsic muscles for every glance of the eyes that departs from direct intersection with the poles of the lenses.

For instance, when +5 dioptry lenses are being worn for distance, a glance of only 2 mm. to the right of the lens-center causes 1^{Δ}, base in, before the right inner rectus and 1^{Δ}, base out, before the left inner rectus, thus effecting easement of the former while taxing the latter. Every person wearing glasses similarly imposes upon his lateral adaptability to some extent and which, of course, will depend upon the power of the lenses being worn and the extent of the excursions of the visual lines from the lens-centers.

Although in hyperopia[5] the exerted accommodation is always in excess of the associated proper convergence for *distance*, it will be demonstrated that such disproportion may not be constant, even with the same patient, for convergence to lesser distances than 6 meters. In fact, as will be later shown, the required accommodation may be less than the associated proper convergence for the reading distance. Such status leads to a much desired *objective* method of detecting it and determining the proper power of the lenses for reading.

Let us consider the same case, in which the facultative hyperope is called upon to exercise his accommodation for reading at, say, 1/3 of a meter. At this distance the binocular

[5] For obvious reasons, greater than 1/6 of a dioptry.

convergence between the visual lines is 6 *m a*, and the required accommodation is +3 dioptries +1 dioptry, the latter amount being the enforced excess of accommodation necessary to correct his facultative hyperopia. Thus, he will use 4 dioptries of accommodation for reading at 1/3 of a meter. So long as he is able to maintain the 4 dioptry effort without fatigue, and still has one-third (Landolt) of his total accommodation in reserve, he will probably be able to read comfortably and distinctly at 1/3 of a meter. Therefore, in this instance, the distance correction of +1 dioptry lenses will also suffice for reading, presuming, of course, that his total accommodative power is 6 dioptries, or nearly so.

It frequently occurs, however, that the enforced 1 dioptry of accommodation, necessarily used in addition to the accommodation normally required to see at 1/3 of a meter, is more than the hyperope can maintain for prolonged periods of time, and notwithstanding the fact that he may have an amplitude of accommodation even greater than 10 dioptries. That he fails to maintain his accommodation at the reading distance, while using his previously determined distance lenses, is best objectively observed through applying skiametry (skiascopy) at the reading distance, during his required fixation at 1/3 of a meter.

Bowman's essay not being accessible to the author during his confinement in a foreign hospital, it is necessary to quote from memory of information imparted by the late Dr. Swan M. Burnett that, "Bowman first called attention to the use of the mirror under stress of accommodation." At any rate, this has since been enthusiastically exploited, by optometrists in general, as so-called dynamic skiametry. They have variously interpreted its significance, with respect to the true status of the ametropia observed, and which, at least so far as hyperopia is concerned, is said by some of them to be a latent hyperopia that remains concealed during the static test, through a supposed ciliary spasm. In this, however, the writer never did concur.

To make the dynamic test, most observers preferably use the plane mirror, as devised by Mr. Cross, which has attached to it a little target inscribed with small letters of the alphabet, or other *fixation* objects. The patient is requested to read the target-letters, preferably aloud, so as to insure attentive fixation through his previously determined distance lenses, which, together with favorable convergence to 1/3 of a meter, will enable him to see singly, and *perhaps* to read the letters with more or less distinctness. The observer thus discovers whether or not the pupillary shadow is devoid of motion *with* the mirror. If the patient is in perfect convergence and accommodation at this distance, 1/3 of a meter, and up to 1/4 of a meter, there will not be a shadow movement. In other words, the patient may read distinctly and comfortably at the point of reversal, since it is conjugate to the foveae and should remain so up to 1/4 of a meter, the chosen near point.

On the other hand, if there is a shadow movement, usually *with* the mirror, it is evident that the accommodation is *less*[6] than should be associated with the convergence to 1/3 of a meter, and which contradicts the excess of accommodation known to be required by hyperopia at a distance. This is, at first flush, perhaps perplexing; yet why should it be? Certainly, extravagant use of accommodation at the remote end of the median line should be credited with at least some depletion of it at the proximate end. Therefore, it simply means that, while the hyperope is in convergence for the object viewed at finite distance and sees it singly, he is, nevertheless, not in perfect accommodation for it at the same place. In other words, his foveae, m and m_0, Fig. 6, are conjugate to two points, p and p_0, respectively, that are situated upon the visual lines, yet beyond the point, P, for which they are converged. This, of course, means that the

[6] Prof. Charles Sheard says of this: "There is always a lag, skiametrically at least, of the accommodation behind the convergence." See page 11810, *American Encyclopedia of Ophthalmology.*

letters upon the mirror-target, while being correctly recognized, are not distinctly defined at the foveae, m and m_0, though the visual lines are converged to the point, P, where the definition should be sharpest.

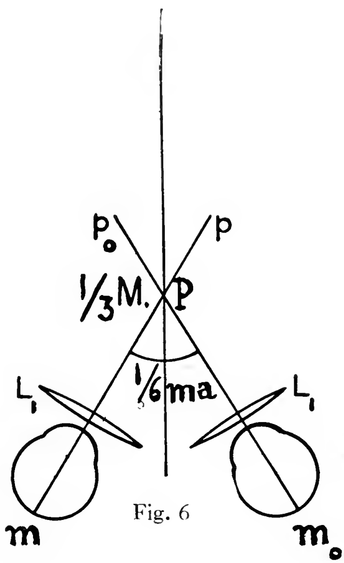


Fig. 6

In Fig. 7 it is made clear that the lens, L_2, before each eye, as an amplification, added to the distance lenses, L_1, causes the points, p and p, to be brought nearer and fused with the point, P, thus harmonizing the accommodation with convergence to the same place. Even in the event of a considerable amplitude of binocular accommodation, say, 10 dioptries, or more, it may, nevertheless, be found that a required amplification of the distance lenses, for instance, of + 0.75, or more dioptries, may be necessary for varying distances, up to the near point, in order to so link accommodation and convergence together as to bring about the required harmony between them for each point, P, P_1, P_2, etc., as each of these points successively follows the other upon the median line.

The need for this comparatively slight lenticular amplification of the distance lenses for reading, in a case having, say, 10 dioptries of accommodation, is probably a surprise to most readers, yet the author has prescribed it many times, with great success, and merely because it does insure conjugacy of the foveae with the points of fixation at every point of convergence up to the near point, the termination of the amplitude of accommodation. And only then is the full amplitude of accommodation at any age made efficiently

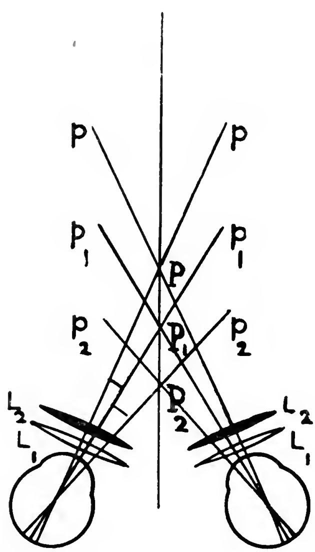
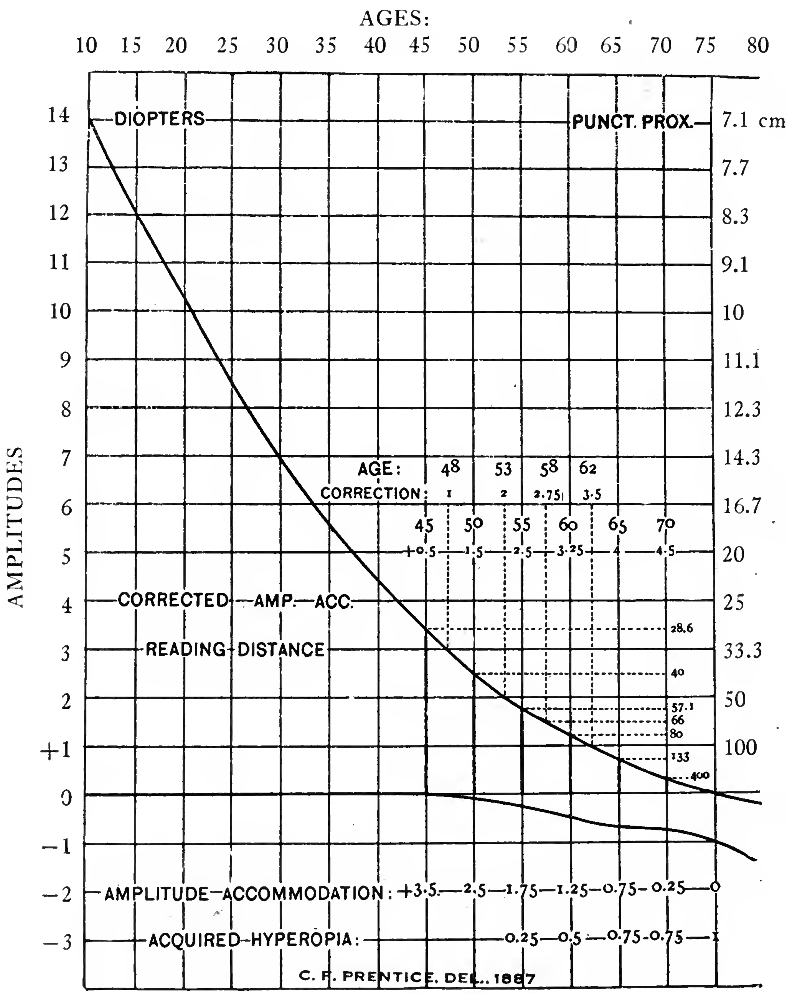


Fig. 7—Lens L_1, Hyperopic Correction. Lens L_2, Amplification

available. This may be easily verified during the subsequent subjective reading test, through measurement of the assisted binocular amplitude of accommodation by means of the dioptral tape.

In fact, the author has habitually, for a number of years, and in the actual presence of students at Columbia

Static and Dynamic Refraction in the Emmetropic Eye (Donders). Corrections for Presbyopia to 25 cm. (Prentice)



University, correctly estimated the ages of persons, to within a year, in fully eighty per cent. of the cases examined, and merely through comparison of the found assisted amplitude of accommodation with the age at which it should normally exist in the accompanying chart of amplitudes. Landolt's dynamometer, with the author's housed electric lamp and attached dioptral tape, is an extremely useful and convenient instrument to be used for this purpose. It is to be understood that the found amplitude of accommodation, in every case of ametropia, is the result of the amplification made necessary in the dynamic test, and which found amplitude, having been made fully effective through the amplification of the distance lenses, is the one that leads to a reasonably correct estimate of the age.[7] If this estimated age is secretively recorded on paper before asking the patient his age, and both figures are subsequently compared by him, he will experience such surprise as to have gained untold confidence in the practitioner's skill.

Of course, it is also quite possible that convergence is being maintained with exceptional difficulty, so that there may also be unsuspected weakness of the interni to contend with, and all of which will depend upon the knowledge necessarily obtained through tests of the powers of adduction and

[7] Example in Hyperopia. Static skiametry gives, say, +1 dioptry, and the subjective verification proves its correctness. Dynamic skiametry calls for amplification, through the addition of +0.75 dioptry lenses, so that the reading lenses are to be +1.75 dioptries.

Subjective verification by Dynamometer, or printed dot-test: Armed with +1.75 dioptry-lenses for reading, during convergence to the dot of the Dynamometer, which is placed on the median line, the location of the punctum proximum is determined when the dot begins to blur, as it is brought nearer to the patient's nose. At this moment, measurement of the distance between the eye and the dot on the visual line gives, say, 8 dioptries on the dioptral tape. The horizontal line at 8, on the left side of the chart, intersects the descending curved line at a point about midway between the ages of 25 and 30, at the top of the chart. The conclusion would be: The patient is 27 1/2 years of age. The same method is to be applied in myopia, astigmatism, etc., the amplifications of the distance glasses always being obtained through superposed convex lenses. Such additions in the trial frame are never detrimental to the optical result, when the lenses are very thin and comply with proper lens optics.

abduction, which after all determine the range of lateral adaptability, of the extrinsic ocular muscles. In this event, the attempt to estimate the age of the patient may prove futile, as it frequently also does for persons who have suffered injuries to the head, or who are convalescing from illness, or who may be on the verge of an attack of illness, typhoid, for instance. Moreover, the existence also of an impaired *convergence* must be conceded, so that its discovery will necessarily modify the conclusions to be reached by the practitioner, whose judgment and experience must lead him to decide whether the impairment of convergence is accompanied by amblyopia of one eye that suppresses the image to avoid manifest diplopia, or whether it is caused by muscular paralysis that may or may not be transitory, etc., etc. In any event, diplopia is not long tolerated, so that suppression of the image of one eye, usually the eye of lesser acuity, is the denouement, unless recovery of the convergence-impairment should be spontaneous. In such instances the application of lateral prisms is useless, and, in fact, would only retard recovery.

However, initially and in general, the observer with the mirror, undaunted, adds to the distance lenses, the lens before each eye that neutralizes the shadow movement during binocular fixation at 1/3 of a meter, as well as up to 1/4 of a meter, and concludes that the discrepancy between convergence and accommodation, as represented by the amplifying lenses, is merely an indication of an inharmonious relationship between convergence and accommodation at *finite distance*, and that has been acquired through prolonged adaptive training of the extrinsic and intrinsic muscles. Failure to maintain at least a comfortable degree of relativity between the powers of convergence and accommodation is, therefore, generally the cause of asthenopia. In fact, Landolt says: "We are not to be surprised if we occasionally meet with a lack of harmony between convergence and accommodation. Moreover, ametropia may reach such

degrees that convergence becomes insufficient in myopia and the accommodation inadequate in hyperopia."

In any event, and in all conditions of ametropia, the mirror, dynamically applied, provides the most convenient and effective objective means by which such lack of harmony at finite distances may be detected and the powers of the lenses for reading may be determined. Thus, for instance, it may occur that the hyperope, of 1 dioptry, *at any age under* 40, may require the addition to his distance glasses of from + 0.5 dioptry to 1 dioptry, or even more, so that the lenses for reading may be as high as + 1.5, or + 2.5 dioptries. The lenses thus prescribed should enable the patient to read up to the near point accredited to his age on Donders' chart of amplitudes. But, in persons over 40 years of age due regard must be had for the distance at which they habitually read, so that amplification of the distance glasses for reading must not be greater than will, at the reading distance, allow of 1/4 to 1/3 of the total accommodation to be held in reserve. All these deductions, of course, are also to be verified by means of the dioptral tape during the subjective test.

However, and in all cases of ametropia, the rule for procedure is extremely simple: First estimate the refractive error by means of static skiametry, and verify it by the subjective test, in order to determine the powers of the distance glasses. Then apply dynamic skiametry, while the distance lenses are still in place, in order to determine the amount of positive lenticular amplification that shall be made in them for reading, or close occupation. It is also emphasized that only the patient's distance glasses are to be worn during the dynamic test, and no empiric additions or subtractions are to be made in arriving at the amplification required for reading. Dynamic skiametry must be an exact procedure, or it is useless as a scientific means of reaching definite conclusions. Seeing is believing. Correct what you see. This method effectively supports the author's contention that convergence of the visual lines and

accommodation at any age should be made to correspond to the same points in the reading plane, or at the usual occupation distance, irrespective of their relative proportions to each other, and which are after all only proportions that are acquired through enforced habit to accomplish vision under the handicap of an ametropia, which is usually also the principal cause of the ensuing asthenopia.

Based upon this principle, the author has applied the stated method through which the required amplifications for reading are to be made in every revealed case of ametropia, even in children, whose amplitudes of accommodation are known to far exceed 10 dioptries; such amplifications being, of course, in direct violation of well established precedent. They were at first very reluctantly made, but the results obtained proved the reliability of the method, so that the author finally became convinced that this practice was at least feasible, convenient, and efficacious, if not altogether warranted by his previous conceptions, which were naturally founded upon the teachings of our most eminent authorities in physiologic optics.

Incidentally, it may also be stated, that, it has always been the author's practice, when prescribing lenses for distance, to secure the highest attainable visual acuity with the greatest clearness, as, in his opinion, more patients have been lost to the practitioner through his having prescribed glasses that fog, than from any other cause. Persons are entitled to the fullest enjoyment of their visual powers, and it should be the skilled practitioner's ambition to secure for them every attainable degree of visual acuity, without imposing disagreeable phenomena of any kind.

Without presuming to suggest a royal road to success, much less to formulate a rule without its exception, the author unhesitatingly asserts that, through careful application of the outlined principle, applied to dynamic skiametry, he has, at least in the past, succeeded in providing persons with satisfactory reading glasses who had previously failed

to get them, and merely because they had usually been advised to wear their distance glasses for reading.

Thus, the end seemed to justify the means; wherefore, this general information is finally revealed, upon my retirement from practice, for the benefit of the thinking active practitioner, who may at least find a profitable place for it among the multitude of opinions that have gone before.

A Quantum Theory of Vision*

Prof. J. Joly, F. R. S.

THE Theory of Vision herein described originated in views respecting the origin of the latent image which formed the subject of an address to the Photographic Convention of the United Kingdom in 1905 (*Nature*, vol. lxxii, page 308). Some couple of years before the war I returned to the subject and made experiments on the retinas of oxen and sheep, believing that it might be possible to detect electrons liberated by visible light falling on the retina or on the black pigment. The results were negative. The war interrupted further experiments, but more recently Mr. J. H. J. Poole, using more sensitive apparatus, examined the black pigment of sheep and oxen as well as the fresh retinas of frogs in a state of dark adaptation. These experiments also gave negative results. Further consideration of the whole matter has convinced me that such a surface emission of electrons was hardly probable under the conditions attending the experiment: conditions which involve the unavoidable presence of surface impurities. The failure to detect liberated electrons by no means invalidates the theory herein discussed.

Dr. H. Stanley Allen, writing to *Nature* (Oct. 30, 1919), refers to a theory of colour vision which on January 7, 1919, he communicated to the Röntgen Society. In this theory he supposes "that photoelectric action takes place in the rods or cones, so that we have a separation of electrons resulting in electrification of the nerve-cells which set up the nervous impulse to the brain." An essentially similar

*This article was transmitted by the author to the editor of this *Journal.* It has since made its appearance in the English publication entitled *The Philosophical Magazine* (vol. xli, p. 289-324, 1921). Its publication in this *Journal* therefore carries the permission for its use on the part of both the author of the article and the publishers of the *Philosophical Magazine.* The essay is in every way worthy of perusal by all those interested in vision. ED.

suggestion was made by Sir Oliver Lodge at the meeting of the British Association in 1919.

(1) I assume that the origin of luminous vision and of colour vision is to be sought in the liberation of electrons under light stimulus within a photoelectric substance or substances existing in the retina. The rhodopsin is such a photosensitive substance. In the case of the rods (in which rhodopsin is found) this substance acts as the basis of vision. In the case of the cones the same substance is very probably responsible. A strong argument for this view is to be found in the fact that in the fovea, where only cones exist, the spectral range of vision is in fair agreement with the spectral absorption of the visual purple or rhodopsin [see (8)]. Further, Kühne states that the maximum spectral absorption of this substance is at that part of the spectrum which seems brightest to the eye, and which is most active in bleaching the rhodopsin. It seems, therefore, very probable that all over the retina it is this substance which forms the intermediary between the light and the nerve; translating the quanta of light-energy into nerve-stimulus.

It is an important feature of the theory herein advocated that the sensitiser in the case of the cones—as the organs of colour vision—should lie outside the cone and should not exist within it as in the case of the rod. That it does not exist within the cones is agreed by all observers. Dr. Edridge-Green (*The Physiology of Vision*, 1920, p. 43) claims to have seen the unbleached rhodopsin between but not in the cones of the fovea. He states that when the retina was first examined the fovea was the reddest part of the whole retina. He also calls attention to a confirmatory observation of Kühne's in the case of a shark's retina. Mr. J. Herbert Parsons more recently points out that Hering had recognized such a distribution of rhodopsin as possible (*Brit. J. Ophthal.*, July, 1920).[1]

[1] Dr. Edridge-Green believes that vision is due to photo-chemical action progressing in the rhodopsin surrounding the cones. He considers that the rods are not percipient.

I assume that in the case of the rods the sensitiser is operative within the nerve. In the case of the cones it is operative from without.

(2) The belief is gaining ground that photo-chemical and photo-electric processes are fundamentally alike (Lewis, *Physical Chemistry*, iii. p. 134). In the case of photographic actions the view that the movement of electrons within the light-sensitive film is responsible for the phenomena observed is supported by facts regarding the various modes in which the plate may be stimulated and by the formation of the latent image. No other theoretical basis affords so general an explanation of the effects of the light. (See *Photo-Electricity*, by H. Stanley Allen: Longmans Green, 1913.) The range of photographic "vision" may be controlled by the use of a sensitiser. This substance is one which absorbs vigorously in one or more special regions of the spectrum. It sensitises the plate to the same range of wave-lengths as it absorbs. The photographic sensitisers are rich in light-absorbing molecules: chromogens. They are photo-electric: emitting electrons over the range of frequencies which they absorb.

(3) Among the well ascertained facts of photo-electric science the following concern the present theory. (a) The electron is liberated with a velocity which, normally, depends on the frequency of the light only: increasing as the wave-length diminishes in such a way as to render the kinetic energy a linear function of the frequency. (b) The velocity is independent of the intensity (amplitude) of the light. (c) For equal intensities of light of different frequency, the light of highest frequency liberates most electrons. (d) For lights of the same frequency, the number of liberated electrons increases with the intensity. (e) The electron in most cases absorbs one quantum, the value of this quantum depending on the frequency according to the well-known equation $\epsilon = h\nu$, where h is Planck's constant ($=6.57 \times 10^{-27}$ erg sec.) and ν is the frequency. In virtue of the absorbed energy,

the electron acquires a certain velocity and pursues a certain free path in the medium till diverted by collision.

(4) The value of the mean free path of electrons taking part in photo-electric emission from platinum has been determined by Robinson (*Phil. Mag.* 1912, 1913). He concludes that it is of the order 10^{-7} cm. Partzsch and Hallwachs (*Ann. d. Phys.* xli. p. 247, 1913) concluded that 99 per cent. of the photo-electrons from platinum emerge from a layer thinner than 28×10^{-7} cm.; from which we may conclude that the maximum range is about of this value. Patterson (*Phil. Mag.* 1902, iii. p. 643, iv. p. 652), dealing with the electrical conductivity of thin metallic films, arrives at the conclusion that the mean free path in various metals, including carbon, is of the order 10^{-6} cm. He cites a result by Vincent (*Ann. d. Chem. et d. Phys.* xix. p. 421, 1900) that for silver the mean electronic free path is 6×10^{-6} cm. Vincent's result also is derived from measurements of resistance.

Such of the above determinations as are based on direct photo-electric measurement, using ultra-violet light, require correction for the less value of the quantum associated with visible wave-lengths: that is, if we assume the penetrating power of the electron is dependent on its velocity. On the other hand, judging by the influence of density on the coefficient of absorption of β electrons, a correction for density may be necessary when we venture to so far exterpolate as to apply results on platinum to aqueous solutions of low-density molecules such as the fluid of the retina. Applying these corrections to the deductions of Robinson and to those of Partzsch and Hallwachs, we find the mean free path in water for electrons supposed to carry the quantum for yellow light to be 5.5×10^{-7} cm., and the maximum free path to be 154×10^{-7} cm. These are, of course, only approximations and must be regarded as only admissible in the absence of more secure results. The quantities arrived at by Patterson and by Vincent for the mean free path would assign to it a value from five to ten times the above, even if we make no

assumption as to the influence of density. A correction on the score of initial velocity is not called for, as the initial velocity affecting Patterson's deductions is about 7.6 x 10^{-6}cm.: a value not greatly different from that acquired by electrons carrying quanta associated with visible light.

Respecting these figures, we must of course bear in mind that the "collisions" refer in general to a deviation of path, not an arrest of motion and loss of energy.

(5) The velocity just referred to as acquired by the electron when a quantum of energy is imparted to it by visible light is very great—of the order 10^7 cm. per sec. The course of the electron before its kinetic energy is given up in work of ionization, in thermal agitation, or otherwise, is a brief one; probably less than the billionth of one second.

(6) The rods contain the sensitiser in the form of rhodopsin. I assume that this substance emits electrons in the same manner as other light-absorbing and optically unstable substances.[2] The electrons set free from the sensitiser by the rays absorbed expend their kinetic energy in stimulating the nerve, and, perhaps, establish an electronic current into the ganglion cell with which the nerve makes connection. I assume that the electronic emission in the rod constitutes an intimate and generally copious source of stimulus—the light being very completely absorbed. The conditions are therefore very favourable to the appreciation of feeble illumination.

In this association of the photosensitive substance with the nerve, the quantitative value of the stimulus is developed at the expense of its qualitative nature. Colour will not be interpreted to the brain, or only defectively. The liberated electrons are in no degree selectively presented to the nerve. All that escape from the rhodopsin molecules contribute to the total stimulus. In the case of some the

[2] Kühne dwells on the remarkable instability of rhodopsin towards light and its great stability towards chemical reagents (*Photo-chemistry of the Retina and on the Visual Purple*, 1878).

energy of the quantum is all but spent; others reach the nerve possessed of the maximum kinetic energy. The stimuli may overlap in time and space. It is probable that some quanta are expended in conferring purely thermal movements on electrons, and along with the destructive effects of quanta upon the sensitiser the regeneration of this must all the time be progressing within the nerve. A confused flow of stimuli, too impure and too crowded for analysis, is the outstanding character of the sensory contribution of the rod. It corresponds to noise in the case of audition. Nevertheless, the conservation and integration within the rod of the stimuli arising from the interaction of light and sensitiser render it a most sensitive exponent of luminosity reaching the retina.

Its sensitivity is, indeed, extraordinary. Henri and des Bancels have shown that the retina is sensitive to an amount of light energy of the value of 5×10^{-12} erg. Now the quantum for green light is 4×10^{-12} erg. We may assume, therefore, that one quantum is sufficient to excite vision (Bayliss, *General Physiology*, p. 512). That is to say, the liberation of a single electron by green or blue light will excite visual sensation.

Again, consider the following relatively commonplace case. A standard candle removed to a distance of 3000 metres projects on each square centimetre luminous energy of the amount 4×10^{-7} erg per sec. This luminosity will evoke vision; and such feeble radiants are known to be best appreciated when the image falls on parts of the retina rich in rods. How many quanta are involved in this excitation of vision? The pupil admits, say, the luminosity reaching one-half a square centimetre or 2×10^{-7} erg per second. This corresponds to about 7×10^{4} quanta per second; such quanta as would be associated with yellow light. The number of rods which receive this energy is considerable. The size of the image is indefinite, but it will not be a point image. Suppose it covers one-tenth of a square millimetre, we can

roughly estimate the number of rods involved. The total area of the retina is about 1000 square millimetres, and the total number of rods has been estimated as 130 millions, and again as half this number. We shall take the number to be 100 million. There will be about 10,000 rods illuminated. The quanta are in fact distributed over this number of rods: that is, 7 quanta enter each rod per second. We may translate this into 7 electrons liberated in each rod per second. It is evident that these small individual stimuli must be so far conserved as to make their way to the optic nerve. If they did not do so but died out within the nerve, there would be no vision. We have it then, however wonderful, however incredible it may seem, that the stimulus arising from one quantum must constitute an appreciable fraction of the threshold stimulus.

(7) The cones are structurally different from the rods in that they contain no visible quantity of rhodopsin. Further, they differ in that each cone is connected through a separate ganglion cell to the optic nerve. This prevails in the fovea where only cones exist and where color vision is at its best. Throughout the retina, on the other hand, the rods are grouped; several individuals contributing their stimuli to the one ganglion cell. This fact is often referred to as accounting for the sensitivity of the foveal area. It is very significant. It reveals an effort of Nature to husband and conserve the cone stimuli and to convey them undiluted to the brain. It suggests that these stimuli are more delicate than those coming from the rods, and are of such a character as to bear no intermingling with other stimuli.

It is also noteworthy that in the central fovea the cones lose their characteristic conical form. They attain a remarkable length, at the same time diminishing in diameter till the latter sinks as low as one micron. Taking the diameter of the outer segment of the cone at this latter figure, and the length as 45 microns[3], we find the surface amounts to 180 times that of the cross section.

[3] Greeff's drawing, according to Schafer, underestimates the length of the cone. On the drawing it is 38 microns. See Quain's *Anatomy*.

To what is this remarkable effort after surface to be ascribed? If we assume the light entering the cone at its inner extremity to be uniformly distributed throughout the cone, it must escape laterally with a luminous intensity reduced 180 times. Plainly there is some advantage on the score of sensitivity in this diffusion of the light. In the central fovea we are told that the cones are so closely packed as to take on a prismatic form where the inner segments approximate one to another. The light must, therefore, at least for the greater part, move as I have indicated.

I assume that the outer segment of the cone is bathed in a photosensitive fluid, probably—almost certainly—rhodopsin. In this the light is absorbed: either directly at the surface of the cone or within the thin layer which separates cone from cone. At the meeting of the cone surface with the sensitiser electrons are emitted. They will also be emitted at such distance from the cone surface as the light can penetrate. Some of those freed at the surface enter the nerve with maximum velocity and kinetic energy. Those liberated more deeply enter the nerve with diminished velocity. Some do not escape from the sensitiser. Others fail to travel beyond the delicate covering of neurokeratin which is believed to invest the nerve. The fastest electrons carry into the nerve almost the full quantum of energy which is characteristic of the frequency giving rise to them. These are the most effective in exciting a nerve stimulus. If the intensity of the light is considerable there are many such. If feeble, there are only a few; but the speed, trajectory, and energy of these electrons remain characteristic of the frequency. Such stimuli are too few and too brief to confuse one with another by overlapping. They are appreciated at their cerebral destination as would be successive notes heard in music.

The penetration of the faster electrons into the nerve must be considerable. A maximum free path of 154×10^{-7} cm. may be assumed. The radius of the cone is about 5×10^{-5}

cm. It follows that electrons moving in a radial direction may traverse one third of the radius before they become deflected. One half the total cross-sectional area of the nerve is traversed by these direct movements. Deviated electrons may be supposed to reach the centre or travel beyond it.

As to the nature of the stimuli arising from electronic bombardment and as to the manner and form in which the energy of the electron is transmitted outwards from the retina to the optic nerve, we have much to learn. The transmission is probably electric in character according to many physiologists. It seems, however, to be probable that the velocity of the absorbed electron is not that which is quantitatively appreciated by the nerve, the time interval involved is far too small. But we may assume that the disturbance set up by the shock is not so short-lived. It travels relatively slowly from its point (or rather line) of origin. Probably what the nerve appreciates is the energy value of the individual stimuli, and this depends on the quantum of energy associated with the electron; which in turn is determined by the frequency of the light, *i. e.*, by its "colour." That each individual electronic stimulus must possess a certain sensory value appears from the figures cited above respecting threshold vision by the rods.

It is necessary to consider a little more fully the specialized nature of the cone functions.

In the central foveal area, covering about 0.16 square millimetres, there appear to be some 2×10^4 cones.[4] Suppose such an amount of light as would certainly excite vision in the rods fell upon this area. I assume that the image of a candle flame, which is 1500 metres distant from the eye, is focused upon the central foveal area and effectively covers this. We now have twelve electrons formed per cone per

[4] Rather more according to Golding-Bird's drawing, if this is intended to depict these organs numerically.

second. It seems safe to conclude that at this distance the fovea would appreciate the candle-flame.

Now it is very evident that enormously greater numbers of electrons might be generated in the sensitiser bathing the cone without risk of overlapping of the stimuli. For not only must we assume that but a small percentage of the received quanta is restored to the cone in the form of what we may call "characteristic" electrons (*i. e.*, those possessing speeds near the maximum speed; in other words, carrying the quantum proper to the wave-length), but we must also bear in mind that the work of each electron occupies at most but a very small fraction of a second.

We have, indeed, arrived at the weak point of the arrangement—its prodigality. Accordingly, we find that Nature, driven to adopt the confusion prevailing in the rods, proceeds now to improve on her design and to develop the cone so as to obtain the maximum number of high-speed electrons. This is effected by increasing the area of the cone wetted by the sensitiser. For the more the activating light is reduced in intensity per unit area (within limits) the less the penetration of the ray into the sensitiser, and the greater the number of electrons released at the immediate cone surface.

Colour vision is in abeyance at very low luminosities. The explanation is that ultimately there are insufficient characteristic electrons to excite the colour sensation. On the other hand, color vision cannot be excited without the diluting effects of the slower moving electrons appearing. For there must always be many (probably a majority of) slow-moving electrons stimulating the nerve. The sensation arising from these is not characteristic of the frequency which gives rise to them, and a sensation of white light is the result. The colour fails to be "saturated." White sensation is always added to the colour sensation excited by the characteristic electrons. We never experience quite saturated colour sensation.

It will be gathered that the present theory ascribes quanti-

tative sensitivity to the rods; qualitative sensitivity to the cones. The difference being mainly referable to the fact that in the one case the sensitiser is located within the nerve, in the other it is located without the nerve. The sensory stimulus emanating from the rods is compounded of many sources of stimuli, *i.e.*, such as may originate in electrons possessing every velocity and kinetic energy up to the maximum proper to the frequency of the activating light, such as may arise in electronic movements associated with the regeneration of the sensitiser and in thermal electronic agitation excited by the quanta taking part in these operations. The stimulus emanating from the cones, on the other hand, is purified of all stimuli save those arising from the kinetic energy of electrons, which are activated by the energy of absorbed quanta. The electrons are, in fact, selectively presented to the nerve: all other sources of stimuli take place outside the cone and are cut off from it by the filament which invests it. In the cone the more intense stimuli tap out to the brain the sensation of colour which we associate with the intensity of the quanta involved. To this succession of characteristic nerve impulses there is added an underlying accompaniment: the white or luminous sensation made up of all the feebler electrons which impart to the nerve but a fraction of that which is characteristic of the frequency of the light entering from the world without. The cone is the more highly specialized organ of the two and is probably a more recent product of evolution.

(8) The higher luminosity of the colour threshold arises out of the conditions affecting the stimulation of the cones; the sensitiser being external and hence a part only of the evoked electrons producing visual sensation. In the rods all absorbed radiations are expended on exciting the sensation of luminosity; the electrons being liberated within the rod. There will be a colourless interval attending foveal stimulation of low intensity for the reason that the characteristic electrons constitute only a fraction of the stimulus and it

requires a certain density of such electrons before colour vision is experienced. In other words, the achromatic effect of very low light intensities or of very brief exposures is due to commencing stimulation by non-characteristic electrons.

(9) One consequence of the different disposition of the sensitiser respecting the rod and the cone is that the characteristic quanta stimulating the cone cannot possess the full energy value proper to the originating frequency. That is to say, it reaches the nerve with a quantity of energy such as would be associated with a frequency ν', less than ν. This is because the electron in the case of the cone must part with some of its energy in penetrating the outer sheath of the cone. We may expect from this that the entire luminosity curve of photopic vision will be shifted towards the red end of the spectrum. This, according to the present theory, is the explanation of why the photopic luminosity curve does not quite coincide with the scotopic luminosity curve; the maximum of the first being at D, nearly, and that of the second being at E (Abney, *Colour Vision*, p. 103). Working from these wave-lengths it is easy to show that the electron must lose about 0.3×10^{-12} erg in penetrating the sheath; *i.e.*, almost 10 per cent. of its energy. It is, according to the quantum theory, quite unnecessary to seek for any other sensitiser than rhodopsin as the basis of vision.

(10) It is probable, according to the present views, that both rods and cones functionate by transmitting electrons from the sensitiser into the optic nerve. The observed current from fundus to cornea attending the light-stimulation of the excised eye finds explanation in the present theory. Bayliss (*loc. cit.* p. 522) reviewing the researches of Waller, Einthoven and Jolly, and others, says:—"Respecting the results of these researches the main fact is that, in the uninjured eye of the vertebrate, the incidence of light causes an electrical change in such a direction that the nervous layer of the retina becomes electrically positive to the rod and cone layer." It will be seen that this points to the

liberation of free negative electricity in rods and cones attending the light stimulus, *i.e.*, to the presence of free electrons in these terminal organs.

(11) Chemical effects have been observed as taking place in the retina when adaptation is changed from dark to light: *i.e.*, there is a change from alkalinity to acidity. This may be involved in the loss of an electron by the ion HO_{-} and the formation of the ion H_{+}.

(12) The movement of the cones attending light stimulus, which in the case of most animals certainly occurs, and which occurs in the case of man, may be a mechanism designed to bring the cones into un-exhausted sensitiser; the bleaching of the immediate layer touching the cone being fatal to its full and proper activity. The rods carrying the sensitiser within would not profit by such a movement, and accordingly do not exhibit it.

(13) Mechanical effects, such as pressure, appear to liberate electrons and produce the latent image on a photographic plate. The luminous sensation attending pressure of the eyeball may arise in the same way: *i.e.*, by the mechanical liberation of electrons. It can be referred to what is known as triboluminescence.

(14) The degree of spectral analysis attainable according to the foregoing theory of colour vision must be limited. The interpretation of colour is referred to the appreciation by the nerve of the value of the quantum. A complete detailed analysis of the whole gamut of wave-lengths between red and violet on such a basis is, probably, unattainable, even if it was any benefit to the organism. And if attainable it might result in badly differentiated colour sensations. The evolutionary growth of three highly developed colour sensations corresponding to the central and mean quanta of the spectrum is the result. It is Nature's compromise with her limitations. It is one which is, in part, cerebral in character: the light-sensitive part of the brain accepting as interpretive of the many separate frequencies a commingling

of sensations excited by the central and end frequencies. These views do not preclude the possibility of more than three primary colour sensations existing. I assume, however, that red, green and violet are alone primary. If, now, rays of the wave-length 5893 A. U., say, are received on the retina, no sensation special to this wave-length arises, although electrons having velocities quite peculiar to it activate the nerve. It is more efficient for the organism to develop special sensitivity towards three representative stimuli, produced by widely differentiated quanta. Thus we feel so much red sensation according to the proximity of λ 5893 to λ 6565, and so much green sensation according to its proximity to λ 5461. The combined sensations we call yellow, and yellow becomes a distinct sensation, although it may be really compounded of two other sensations. It is a sort of unconscious memory: the one stimulus "reminding" the colour-visual centre of the stimuli which evoke the representative sensations, red and green.

Of course it would be easy to imagine a purely objective explanation of colour vision if rhodopsin exhibited appropriate absorption bands. But, on the contrary, its absorption spectrum is remarkably uniform over the range of the visible spectrum.

(15) A colour-blind individual is one whose foveal nerves respond feebly to certain quanta. The same abnormality affects the cones all over his retina. Thus if he is violet and greenblind, the quanta proper to E or to F produce only a feeble stimulus. But those proper to C and D are fairly normal in the stimulus they excite. His brain has developed no more than the one sensation, the maximum luminosity of which lies between E and D. The abnormality is fundamentally a physical deficiency; and this leads to mental deficiency, as commonly happens in similar cases. Colour vision curves constructed from the examination of abnormal sight show the curves as overlapping. As I have already pointed out, the entry of spent electrons into the normal

nerve *i.e.*, electrons possessing less kinetic energy than is proper to the wave-length illuminating the retina—introduces indeterminate stimuli which result in luminous or white sensation; for such, received in the sensory colour-centre, could not be differentiated from the sensation arising when white light falls on the retina, and quanta exciting all three colour sensations stimulate the nerve. Such spent electrons affect the sensations of the colour-blind also, according to his limitations. They can give no new sensation to one possessed of monochromatic vision. The subject is full of obscurities and difficulties, and I shall not enter upon it. I see nothing in the present theory to accentuate or add to those difficulties. It is to be hoped it may contribute to clearing them up.

(16) The spectral limits of the colour-sensation curves find a simple physical explanation in the failing absorption of rhodopsin for these wave-lengths. This matter is, of course, bound up with the limitations imposed by the absorption of quanta (associated with the higher and lower frequencies) by the media through which the light has to pass before it reaches the retina.

(17) The light-sensitive substance, rhodopsin, is probably extremely complex. It is said to be related to anthocyanins which are rich in chromogens and are held accountable for a wide range of colour in flowering plants. Evidence for the richness in chromogens of rhodopsin is, I think, to be found in its sustained absorption of visible spectral rays. "Fatigue" may evidently be referred to the exhaustion of such chromogens as have been deprived of an electron. This appears to be the natural explanation.

(18) When a bright object is looked at for some time and the eyes then closed, "after-images" are seen. These are both positive and negative.

The phenomena of positive after-images suggest that something of the nature of the latent photographic image is formed in the nerve-substance. Indeed, *a priori*, one would expect

this to happen, the conditions having much in common in the two cases. On this view electrons entering the nerve would in some cases remain attached to atoms within its substance and an electrostatic field would prevail between them and positive ions in contact with the cone. This system must break down ultimately—probably is continually breaking down and being rebuilt. The electrons attached within the nerve would be distributed at radial distances from the surface proportional to the frequency of the light which gave rise to them. The "red" electrons (*i. e.*, those exciting pre-eminently the red sensation) outermost, then the "green" and lastly the "violet." But in the case of very intense light stimulus the disturbance due to the passage of very many electrons might result in permitting only very few of the red and green, but allowing abundant violet, to collect in this manner; the latter attaining the outer limits of the field of disturbance. Now in the colour succession of after-images there is found evidence for both these modes of distribution. We must suppose that when the light stimulus is withdrawn the electrostatic field gradually breaks down. We have the red electrons going first; for they are the most strongly attracted; the green following, and finally the violet. We assume that in the act of reverting to the sensitising molecule the electron creates fresh colour sensation. But the energy available must be less than that originally possessed by the electron when entering the nerve. Einstein's explanation of the law of Stokes respecting fluorescence (Allen, *loc. cit.* p. 190) may be invoked. In the present case there should be a diminution of the intensity of the stimulus; in other words a shift of the sensation towards the red end.

Now it is agreed by many observers that amidst many variants the after-images appear very generally in the order red, green, blue (Parsons, *loc. cit.* pp. 111, 261). This is for moderate to bright light. For long continued excitation by more intense light, blue takes precedence of all. There is also evidence for a lowering of the spectral sensation. Thus

McDougall writes: "An important feature of the after-images of bright white light is that, after a first short period in which two colours fuse to give yellow, or, as is the case after the brightest light, all three fuse to give white, the colours that in turn occupy the area of the after-image, alone and unchanging for considerable periods, are red, green and blue only. The red is a rich crimson red, decidedly less orange than the red of the solar spectrum, the blue is a rich ultramarine, and the green a pure green having no inclination towards blue or yellow." As regards the repetitional effect generally observed, that is, the recurrence of the three colours in the like order, we again find a photographic counterpart in recurrent reversal. This is, according to the electronic theory of photography, due to the break-down of a succession of latent images; accumulations of electrons occurring till a point is reached when these revert to the parent molecules. But in what manner in the case of the nerve could such effects be stored and saved from immediate degradation? A possible explanation suggests itself. The cone during light stimulus contracts; subsequently it again elongates. When contracting we may suppose the cone moves towards parts of the sensitiser still unacted upon. And this is probably the primary object of the movement. The effect will be to remove the cone from the field of positive ionization and so free the internal, fixed electrons from electrostatic attraction. But when the retina is again darkened the cone moves back into the exhausted sensitiser; a region rich in free positive ions. Hence as it elongates an electrostatic positive field accumulates till there is breakdown and discharge during which the fundamental sensations are successively evoked. If the successive colour cycles attending the movement of the cones overlap there will ensue the irregular sequence often perceived. On the other hand, if the cones move under the influence of a common stimulus and advance, not uniformly, but with pauses of quiescence, then the repetitional colour cycles find

complete explanation; each cycle corresponding to the latent "image" breaking down over one short segment of the cone. That the movement of the cones is general and not due to a stimulus local to each cone is, I suggest, shown by the fact that in the case of the frog, where the cone-movement is very marked, "light on one eye causes reaction on both as also light on the skin so long as the brain is intact" (Engelmann, *Nahmacher*. See Parsons, *loc. cit.* p. 12).

It is consistent with the view that after-images are of the nature of the latent photographic image that they may persist for very considerable time intervals.

The negative after-image is probably explained by fatigue. It appears a little after the positive image, and when the retina is re-exposed to feeble illumination. What was bright now appears as dark and the colours change to the complementary hues.

A discontinuous motion of the cones will naturally arise if the nervous actions involved are reflex in character; as the observations on the frog very surely indicate. In this case electronic stimulus of the cone initiates its retraction and the cessation of the stimulus initiates its extension. Hence when, on the extension of the nerve, the luminous after-image begins to be formed the electronic movements act as the afferent stimulus and extension ceases or contraction may ensue. Only when the after-image dies out is the extension of the cone continued. But now a fresh part of the "latent image" becomes involved and again there is arrestment: and so on.

(19) The momentary electrical response which is noticed in the retina when light is cut off and which is the same in direction as the light response (Bayliss, *loc. cit.* p. 522) is not difficult to explain on the present theory. It is due to the break-down partially or completely of the latent "image" in the cones; that is, to the stimulus which arises when the anchored electrons are attracted back to the positive field surrounding the cone; the electrostatic effects of inflowing

electrons attending light stimulus having ceased to affect them.

(20) Simultaneous contrast effects are, according to my own observations, largely due to imperfect fixation. There is probably a psychological factor also involved. The tissue paper increases the effects of adjacent colour-patches because it renders fixation inaccurate.

(21) The Purkinje effect has been explained by von Kries on the assumption that the cones are sensitive to colour, possess a maximum sensitiveness in the yellow, and are responsible for vision at high luminous intensities; the rods being responsible for vision at low intensities. Into this matter the dark adaptation of the retina enters, for with it scotopic values rise. There is nothing here inconsistent with the unitary theory of vision.

(22) The dependence of the colour-sensitivity of the cone upon its surface area is well shown by the increasing colour-blindness of the retina towards the periphery; the active area of the cone diminishing as retinal colour-blindness increases.

The study of colour vision is hampered by many difficulties, chief among which is the elusive and variable nature of the effects under observation. On this account we find disagreement among high authorities as to many phenomena of vision. I shall not here pursue the matter into further details.

The foregoing theory is founded on the conception of the quantum. The nerve is supposed to discriminate between the quanta of three or more representative spectral centres. And should not the quantum be regarded as a *vera causa*, when we find that a single one of them acting on the retinal nerve suffices to stimulate the sense of vision? What alternatives have we to a quantum theory at the present time? One thing seems certain. No interpretation of colour in terms of the frequency seems possible, whether primary or forced vibrations be appealed to. The late Lord Rayleigh,

in a letter to *Nature* (May 21, 1918), questions the possibility of sound-frequencies of 256 vibrations per second being directly conveyed by the nerves to the brain. "It is rather difficult to believe it," he adds, "especially when we remember that frequencies to 10,000 per sec. have to be dealt with. Even if we could accept this, how deal with light-processes in action along the nerve repeated 10^{15} times per second?"

I have received kind help from many friends. At the time of my pre-war experiments Professor John Mallet Purser gave me much valuable instruction, and since has continually assisted me. Prof. H. H. Dixon, Dr. O'Sullivan, S. F. T. C. D., and the late Sir Henry Thompson also advised me. More recently, I have to acknowledge much assistance in experimental work from Prof. Pringle and his Assistant, Dr. Fearon. Dr. Euphan Maxwell has been so good as to place valuable histological specimens at my disposal. I owe much to my discussions with Mr. J. H. J. Poole.

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Editorials

The Practitioner Himself

SOME time ago the editor found on his desk a printed sheet of paper containing some facts purporting to come from the government bureau of vital statistics and having to do with the average length of life of men engaged in various vocations. As we write these words we do not find the list at hand but we do remember quite distinctly the general facts, namely: that farmers head the list with an average life of 58 years, and so on down through various vocations of more or less mixed, indoor and outdoor life, until we reach the bottom and find that the office worker lives an average life of 36 years. Perhaps one reason why we remember these facts so well is that we repeated them to a fellow-worker, who exclaimed: "I would rather live the thirty-six years and be done with life than live five thousand years on a farm." Perhaps that is so, for each must labor according to his tastes and his capabilities if he is to live his life to the full. These words will, however, be read chiefly by those who spend the bulk of their waking hours in offices--whether these be apartments of practitioners, teachers' classrooms or scientific laboratories. And, with all of our striving to make ourselves more competent and serviceable to others, it is possible that each of us may forget the fact that the most worth-while thing after all is the practitioner *himself*, for the deed without the doer would be impossible and the inefficiency of the physical workings of that organism known as *yourself* may too often interfere with the services rendered to others.

We think that there is no doubt as to the truth of the statement that the practitioner too often fails to appreciate the fact that he himself is the finest piece of capital stock of which he will ever be possessed. Too often he thinks of his

professional duties and his business to the exclusion of himself. He may be possessed of an automobile which he knows he must, if it is to serve him well, keep in good running order; that it needs oil, gasoline, water and air to keep it going and that its life, and the services it can render him, depend upon the care given it. He will keep it clean and polished in order that it may not acquire a tumbled-down appearance. But when he comes to the care of himself and his appearance--well, we simply cannot take the space to write out all the sins of omission and commission. Improper food, too hurriedly eaten; failure to rest the system for a few minutes several times a day, failure to shake off the cares of a busy life--these are a few of the big, little things that make us what we ought not to be. Do we not many times fail to fulfill our duties to those who come to us because we become impatient and irritable, and do we not too often lose the love and respect of our patients simply because we have forgotten, neglected and abused our physical selves?

And just a word or two about the personal appearance of the practitioner himself. Is it not an anomaly that so many who have the privilege of ministering to the bodily weaknesses of others and who glibly and with no difficulty hand out words of advice to others, and who teach the simple doctrines of cleanliness and sanitation, should appear in public places and before patients in their offices, slovenly dressed, with unshaven faces, dirty hands, fingernails in mourning, soiled collars and shoes that are crying for a coat of blacking? Do not cleanliness of person and apparel, as rich as our purses can afford, bespeak confidence in us as practitioners and what we do? And do we not have more confidence in ourselves when we look fit?

Pertaining to the Influence Exerted on Both Eyes by a Single Prism before One Eye

NOT so long ago a practitioner of high repute and excellent practices wrote the editor the following paragraphs:-

"It seems generally acknowledged that a prism placed before one eye divides its influence between both eyes. Do you hold that a prism, base out, before the right eye rotates that eye alone (inwardly) to the full displacement represented by that prism, while the fellow eye (left eye) remains immobile, fixing the object just as it did before the prism was placed before the right eye? This seems logical from one standpoint. In that way we have participation of both foveae. But wherein is the influence divided between both eyes? As I understand it, if both eyes divide the influence, then both interni must be brought into play or both eyes rotate inwardly.

"I note some writers construe it in this way: The eye with the prism before it rotates the full distance represented by the prism, while the fellow eye undergoes a *resistance* pull, so to speak, by maintaining itself immobile. In the matter of the interni being made to pull by a prism, I can see how the eye with the prism, base out, will experience a pull upon the right internus, but for the left eye to be restrained from following its companion eye inwardly, there would not be so much a pull on the left internus to hold that eye immobile as a pull on its antagonistic muscle, the left external rectus. If this resistance developed in the left internal rectus means a sort of inhibition or rigidity that is developed, it seems a little clearer to me, but then it cannot, it seems to me, be strictly proper to refer to such a condition as an equal division in prismatic influence between both eyes.

"The following construction has also occurred to me as being logical: Placing a prism, say base out, before one eye so reacts upon the innervational centers that both eyes turn

inwardly equal amounts and so the displacement of images upon the retinae are accordingly equal with the difference that corresponding retinal points instead of the foveae participate in the binocular single vision. Is that possible? Does diplopia mean a difference in corresponding retinal points upon which images in both eyes are placed, or does it mean alone the absence of either or both images upon the foveae? In other words, when a prism is placed before one eye and the fusion occurs, does binocular single vision mean that both images must be upon the foveae alone to the exclusion of any other two corresponding points?"

In the first place, therefore, it must be borne in mind that convergence and divergence are really very intimately associated: so intimately in fact that it is almost impossible to dissociate them, hence any consideration of one member of this dual family necessarily involves the other also. Suppose, for example, prisms, base in, are employed: then we know that a stimulus to divergence is created. The eye before which the prism is placed is compelled to diverge, in order that binocular single vision may be obtained and maintained; the eye before which the prism is not placed is the fixing eye and maintains the image upon its fovea. Or, to re-state the proposition, we believe that if a prism is placed before one eye only, all of the diverging necessary is done by that eye and that the other eye maintains its direction toward the object fixed. It is, of course, possible, and in fact probable, that the first or instantaneous impulse is for both eyes to diverge, but this is momentary only and the eye carrying no prism immediately asserts its supremacy by reason of the fact that the brain is cognizant of the position of the object seen and will not tolerate a violation of the law of direction.

In looking through the literature for an expression of opinion and belief on the part of authorities on ocular muscles, we find the following paragraph which has been taken from Hansell and Reber's *Ocular Muscles*—a most

valuable handbook which, we are sorry to say, is at present out of print. "When the prism is placed before one eye only, all of the diverging is done by that eye and the other unwaveringly maintains its direction toward the object focussed. Yet it does not follow that the testing is confined to the eye that turns, for the turning eye is held in its divergent position and the other in its straight position by a contraction of all the external muscles, and, therefore, we are, in a certain sense, testing convergence and divergence at the same time. The completed action is really a very complicated one. For example, a 6 degree prism is held, base *in*, before the right eye; in order to overcome the momentary diplopia induced by the prism, the abductors of the right eye are called into play and that eye diverged, as can be seen through the prism. Strangely enough, the left eye is held straight, notwithstanding the general rule that movement of one eye in any direction is always accompanied by a similar associated movement of the other eye—movements induced by prisms not too strong to permit fusion constitute the sole apparent exception to this rule—and that therefore the abductors of the left eye tend to turn that eye in the same direction as its fellow. To neutralize the latter impulse the abductors of the left eye are called upon and their action necessitates, in turn, action on the part of the adductors of the right eye, which would immediately bring the right eye back to parallelism were not the abductors fully occupied in keeping it in such position as to avoid diplopia. Hence the introduction of the 6 degree prism disturbed the divergence primarily and the convergence secondarily. The same phenomenon occurs when prisms are placed, bases *out*, before one or both eyes. In testing supra- or infraduction a similarly complicated act is excited. Thus: when a 2 degree prism is placed base down before the right eye, the image falls on the right retina below the fovea, in consequence of which the elevators contract and the right eye rolls up, turning its fovea until it reaches the position of the displaced

image. Naturally an equal stimulation is sent to the elevators of the left eye (according to the above-mentioned rule for associated eye-movements), but a change in the position of the left fovea would destroy the test so that the upward impulse of the left eye must be met by an equal downward impulse of the right eye, which is prohibitive because of the diplopia that would be sure to follow. Hence, while the elevators and depressors are in equilibrium, they are only artificially and temporarily so. We are in a sense determining the power of elevation as compared with that of depression, but we have been really investigating the limits of equilibrium by prism stimulation of allied and of antagonistic muscles."

Therefore, if the prism which is placed before an eye is not too strong to overpower the function of fusion (in other words, to destroy binocular single vision), the eye before which it is placed will be so rotated that the fovea will be moved from its original position to that occupied by the image. The foveae will, therefore, constitute the corresponding points—or contain such points—involved in the fusion of images under prismatic displacement. We believe that it is obvious that the foveae only could constitute the corresponding points involved in such tests, otherwise there will be no possibility of obtaining such data as are afforded by duction tests for the reason that corresponding points are myriad in number and as a result, if any two corresponding points could function to give binocular single vision in duction tests, there would be different results for different pairs of corresponding points. Possibly such a catalogue of results would follow if all points upon the retinae gave equal visual acuity. But the foveae are supreme in their superiority of acuity. We do get some of the effects we have just rehearsed in cases in which there is a *false* macula which assumes the functions of that portion of the retina.

It follows, therefore, that all ocular muscle tests to be of

real significance and value should be *monocular* in character. That is to say, there should be one eye which may locate the test object or fixation object in its proper position in space and before that eye there should be placed nothing other than lenses correcting refractive errors, if such is deemed desirable by the operator. The eye before which prisms are placed is the eye whose duction powers are being determined.

Furthermore, the rules of conjunction of eyes, so well investigated years ago by Hering, and the statement that all innervations of the eyes are equally divided between the two members, are not at variance with statements which have been made in the foregoing paragraphs. We believe that many who think upon these matters are at a loss to coordinate the statement that the eye before which the prism is placed is the only one which moves, with the statement that the innervations of the eyes are equally divided between the two members. Hering has given us a very simple illustration showing how one eye may remain stationary while the other moves; without in the least impeaching the rule of equally divided innervations. Imagine the two eyes looking straight forward at a very distant object. The visual axis is then to be directed to a near object lying in the line of the right visual axis, so that the right eye has no motion to make in looking at it, but the left eye has to sweep through the necessary angle to give binocular single vision of the near object. Hering has shown that half of the motion of the left eye is due to the converging innervation and the remaining half to the innervation which turns both eyes to the right and that while the two innervations harmoniously coördinate in the case of the left eye, they actually counteract each other in the case of the right eye. For the left internal rectus is stimulated by both and the left external rectus by neither. The right internal rectus is stimulated by one and the right external rectus also by one. Convergence therefore brings both eyes as if to a point on the

medium plane and dextroduction moves them as if from this medium plane point to the near point in line with the visual axis of the right eye. These do not—at least ordinarily—act in succession but simultaneously, so that each increment of convergence is immediately prevented from moving the right eye by an equal increment of force due to dextroduction.

And again, to return to the condition in which a prism is held before one eye, it is found that, after single vision obtains, the object does not appear to occupy the position either of the true object or of the false one existing when diplopia occurs, but lies between the two. In some cases it lies midway between the two. We believe, however, that this is a matter which depends somewhat upon the existence of a dominant or directing eye and whether the prism is worn before the eye or its mate. A person with both eyes open and a prism before one eye will misjudge of the position of objects even though he sees them single. The malprojection will equal only half the deviating angle of the prism. Hence the innervations at work are conjugate.

Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

Samuel H. Robinson, O.D., F.O.S.

Introductory Statement

IN the present treatise on ocular muscle work, the author has been inspired by the desire to communicate first-hand experiences and observations in the practical pursuit of a subject, which, though familiar to many—in a rather vague and abstract manner—has failed perhaps to make a more intimate impression upon those whose work it encompasses, and for whom a most practical field lies wholly within its legitimate sphere of activity.

The author does not seek to advance new optic principles, nor to formulate theories based on the higher speculations or on cultural inferences and deductions. On the contrary, the subject as presented must smack of the commonplace and appear devoid of that mental exhilaration which excursions into less frequented channels very often afford one. No exercise of one's higher intellectuality becomes necessary, and nothing beyond a mediocre mental application—the simple analysis of the relation between several well known optical facts and the eye's functions—need be anticipated. And yet, in spite of the circumstances indicated, a most unexpected wealth of practical value and utility may be gleaned from serious reflection upon the subject which is here to follow.

The writer cannot better express the truth of his convictions in relation to ocular muscle work, than to quote in advance, from a deferred portion of his manuscripts.

"The subject of ocular muscle exercise or treatment has for some time been engaging the thought and attention of

the studious refractionist. To have studied and elaborated for years upon the action of a small intrinsic muscle which controls the focussing adjustments of the eye, and to have practically ignored the coöperative extrinsic muscles whose functions are simultaneous and correlated with that of the ciliary, is quite beyond the comprehension of the modern investigator.

"To be sure, extrinsic ocular functions have been closely studied, and the facts gleaned, systematized and recorded. One is taught, for instance, that there exists a relationship between convergence and accommodation. This subject has been much elaborated upon. There has also been established an accepted standard of duction power for each of the several pair of extrinsic eye muscles. Imbalances are now determined, measured and recorded. In the higher field of ocular muscle investigations, subtle impulses and strange forces are minutely traced to lobes in the brain, there to remain in undisturbed oblivion. But to what purpose is all this?

"There are those who yet oppose muscle exercise. What can be their purpose? Shall we ignore a low state of innervation because there is yet no diplopia or muscular asthenopia? Then we may argue that one or more diopters of refractive error shall go uncorrected because the patient is indifferent to a blur or unconscious of stress or pain in the ciliary body. Or, is it considered better to prescribe prisms? Then it must be better to prolong and aggravate a defect than to eliminate it in whole or part through exercise. Or, again, can it be the judgment that prisms be prescribed in highly weakened states of innervation and lesser defects be ignored? Then it would be equally reasonable to correct high refractive errors and ignore the lesser ones. Shall it be said that refractive correction, alone, can strike effectively at the root of all innervational disturbance? Then the study, experience and close observations of careful students in the field of ocular muscles must be placed at

naught, and the *lens* enshrined as the sole and universal panacea for all ocular anomalies. There can, in fact, be just one answer to these questions. *Give muscle treatment in every instance, where subnormal duction exists, after the proper refractive correction has been administered; prescribe prisms when exercise fails and prism support can alone satisfy the condition.*

"It is well recognized that a substantial degree of refractive error will cause a blur in vision if uncorrected, and when self-corrected may develop strain through the focussing apparatus. In the one case, an improper optical adjustment produces a blurred or indistinct image; in the other, the effort at self-adjustment develops stress and pain throughout the ciliary body. Yet, its replica in the extra-ocular functions is passed practically unnoticed. It has been taught that unless both eyes properly fix an object, diplopia or blurred vision ensues; but somehow, the correlated fact has not been emphasized, that, if the extrinsic muscles undergo special effort in maintaining single binocular vision, strain in these muscles may be expected to follow, as inevitably as that experienced by the ciliary body. Just as an hyperopic eye suffers its greatest strain when used for near work, equally so, does the exophoric eye suffer the severest when at near work. Just as a myopic eye sees least distinctly at a distance, to that degree does the esophoric eye suffer the greatest when looking at a distance. And just as the myopic eye without correction sees clearly at close range, to the same extent does the esophoric eye, though uncorrected, experience a sense of ease when converging for the near point. Surely, there is some significance in all this.

"There are those who contend, that if *exercising* the extrinsic muscles is preferable to *prescribing prisms* for their defects, why not similarly exercise the ciliary in order that it may correct its own defects without strain, instead of correcting the defects with lenses? On the face of it, the

argument appears sound and plausible. Yet, these facts are overlooked. When the ciliary corrects a refractive error, due to an ocular deformity, there is expended through it nervous energy beyond that normally required for accomplishing accommodation in the emmetropic eye. With every act of vision, that eye suffers not through its inability to perform *regular* and *normal* functions, but because of extra and undue accommodation imposed on it. Who knows, but that a form of ciliary exercise may yet prove of some service (especially in early presbyopia)?

"This we know on the face of it. To inaugurate a system of ciliary exercise is to engage on the side of the *abnormal*. It is training and developing the ciliary to perform work beyond that apparently intended by nature. On the other hand, the institution of ocular prism exercise is confined entirely within the field of the *normal*. Here one deals *not* with *anatomical deformities*, but with *suppressed* or *insufficient nervous impulses*. Here one does not attempt to raise the duction power of muscles beyond determined, prescribed standards, but rather to develop innervations so as to meet a normal and essential standard. The purpose and effect of the two types of exercise is obviously dissimilar. In the one case, exercise advocated, will produce an *abnormal* muscle; in the other case, the aim is merely to approach a state of *normalcy*.

"Too few who disparage muscle treatment speak from ripe experience. It is probably safe to state that such persons have never seriously engaged in ocular muscle work. It is more than probable, that after several perfunctory and fruitless attempts, they have abandoned it as a visionary practice, without real merit or opportunity. Too much criticism has thus been foisted upon a *work*, when the same should have been directed instead at the *worker*. * * *

"Practitioners from time to time are questioning the practicability and infallibility of ocular muscle work. In reply it may be stated, that there is no accepted work whose

results are so uniformly invariable, as to preclude a single exception or variation. The practicability of any method must be judged, not by its periodic failures, but by its more frequent and wider range of successes. That which alone can solve a difficult problem, or, which alone, can surmount an unusual difficulty, is worthy of use and may duly take its place in the ranks of the indispensable.

"No type of work is absolutely infallible; nor, can one method uniformly satisfy every condition or situation. In observing ocular muscle anomalies, it is found that various conditions demand various forms of treatment. Oculo-prism treatment does not project itself as a perfect and general panacea for all forms of ocular muscle disorders. A total paralysis of an extrinsic ocular muscle certainly cannot be expected to respond to muscle exercise. Similarly, a partial paralysis, or muscular palsy, may anticipate no response, though an attempt at treatment may sometime be deemed worthy in behalf of study or investigation. The fault of anatomically malformed muscles,—*e.g.*, muscles that are too long or too short,—cannot fundamentally be attributed to deficient innervation; hence, one need neither seek nor hope to find relief through exercise in such anomalies.

"The exceptional cases of *erratic impulses*, which at one time possibly show a state of esophoria, while at another—under the influence of subtle and inexplicable forces—perhaps indicate exophoria or some tropia condition, need likewise *not* be classed as ideal cases for ocular muscle treatment. Just as refraction deals with *ocular functional disturbances* in *healthy* eyes that are *malformed*, and not with *pathological* conditions, so does oculo-prism treatment deal with *subnormal* but *comprehensible innervations*, and not with those disturbances which are the product, perchance, of a *deranged nervous system*, intractable and ungovernable. * * *"

"To some, ocular muscle treatment, as here outlined, may seem conspicuously presented as the only available means

for relieving extra-ocular disorders. Inasmuch as the present text is wholly designed to expound muscle exercise in its own peculiar adaptation to extrinsic ocular muscle insufficiencies and its consequent asthenopia, it should not be interpreted as a defiance to other remedial methods, which may and often should be associated in the interest of desired alleviation. The fact is, that oculo-prism treatment in many cases can supply but a portion of the desired results, unless coördinated with such help as will be further outlined. * * *"

"Undoubtedly neurosis is largely responsible for functional derangement, as is anemia also, in which deficient impulses may be directly attributed to a condition of the blood and subsequently poor nutrition or *vice versa.* But why should these argue against muscle exercise? Shall the anemic be denied the benefit of fresh air, suitable walks and outdoor exercise, because his system requires rehabilitation from within perhaps, as well as from without? What seems truly essential is that both or all forms of correction be utilized for the sake of special contribution to relief and comfort. * * *"

"A deficient innervation in the extrinsic ocular muscles due to a state of general nervous debility or to a condition of anemia should not be expected to respond readily and at times even perceptibly to ocular prism treatment. It is apparent, of course, that any local stimulation afforded by ocular muscle exercise is so slight in comparison to the stimulation required by the entire body, that its effect or influence becomes quickly dissipated; but what is more obvious is the fact that the body itself, which represents the 'reservoir' of nervous energy, is already so thoroughly depleted that it fails to supply even the limited energy necessary to support a successful course of muscular exercise.

"This explains readily why persons who are extremely weak and anemic make unresponsive and unsuccessful subjects for oculo-prism treatment. It is apparent, then, how

essential it is, when exercising ocular muscles, that a sufficient nervous reserve force be provided the body in order that adequate 'ammunition' shall be at hand with which to prosecute the work. It becomes imperative, therefore, that the refractionist when pursuing ocular muscle work, shall in every case be solicitous after the general good health of his patient—both in the interest of the latter's physical welfare and the success of his own labor and treatment."

Perhaps the writer has already provided the reader a forecast of what thoughts have prompted this work. Perhaps too, a clearer view of the real province of ocular muscle work may have been afforded, which will stimulate, it is hoped, a deeper interest in the perusal and study of this work. One fact will become evident, later, namely; that special effort has been exercised to present ocular muscle work in an intimately practical light, with a view that fundamental facts shall be quickly assimilated, and that the willing practitioner may experience little difficulty in readily embracing this work in his daily practice.

Towards this end, the subject matter has been shorn, as much as permissible, of technical and ambiguous complexities, leaving the sterling and essential facts to stand out in bold relief. To better accomplish this, the writer has adopted in portions a somewhat colloquial style, seeking to "bring home" such practically material facts as will leave the student when thrown upon his own resources without that wavering sense of helplessness or uncertainty. Every effort, therefore, though diminutive in character, has been designed to prepare one to engage practically in the prismatic treatment of the ocular muscles.

The writer feels impelled to say with utmost sincerity and veracity, that numerous and joy-inspiring have been the cases of ocular muscle disorders which have successfully passed his hand. The earlier experience had afforded a peculiar sense of ecstasy and revelation, perhaps too unique to bear description. As successive cases continued to yield

quite readily under procedures methodically developed, the author became more and more assured that ocular muscle treatment was not an hallucination nor passing fancy, and the significant correlation between optic principles utilized and the eye's functions as comprehended became more firmly established.

In conclusion, it is well to add, that in the measure that one imbibes the spirit of this work, to that degree may success be anticipated to attend one's efforts.

CHAPTER 1

The Prism and the Eye

EVERY refractionist engaging in ocular muscle work will find it necessary to acquaint himself with the basic principles underlying this work. These will not be found difficult of comprehension.

The prism whose sole property is to deflect or bend rays of light, and the human eye which Providence, through guiding muscles, had ordained shall submit to the influence of the prism are the *two elements* upon which the entire system of ocular muscle work has become possible. In other words, had not the prism the ability to deflect light or was not the eye amenable to the influence of the prism, the field of ocular muscle work would be unknown today, at least as now practised.

We must perceive that a knowledge of how the prism deflects light and how in turn it influences the human eye are of paramount importance. When these few simple facts are understood, we may intelligently proceed with their practical uses or applications.

The Prism

The prism is a wedge-shaped, transparent medium (generally glass) having two polished converging sides meeting in a line called the *apex*. The surface connecting the

divergent ends of these sides is known as the *base*, and towards this base rays of light always bend in passing through the prism. (In Figure 1, A B C D is the *base* and E F the *apex*.)

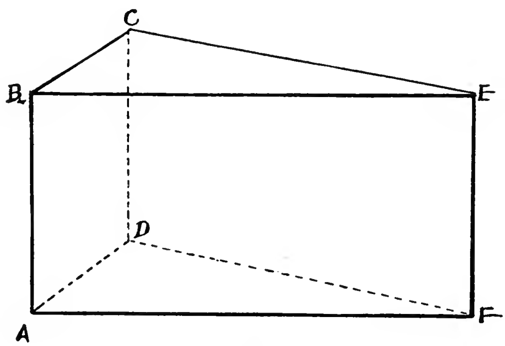


Fig. 1

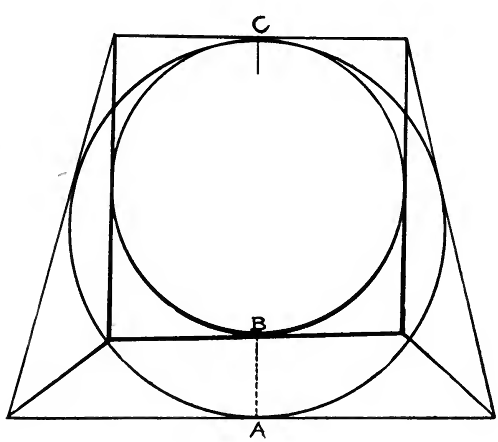


Fig. 1 (a)

The Unit Prism

The *unit* prism power as commonly accepted today is the prism-diopter (P. D.) and represents a deviation in a ray of light one centimeter (cm) for every meter distance the light

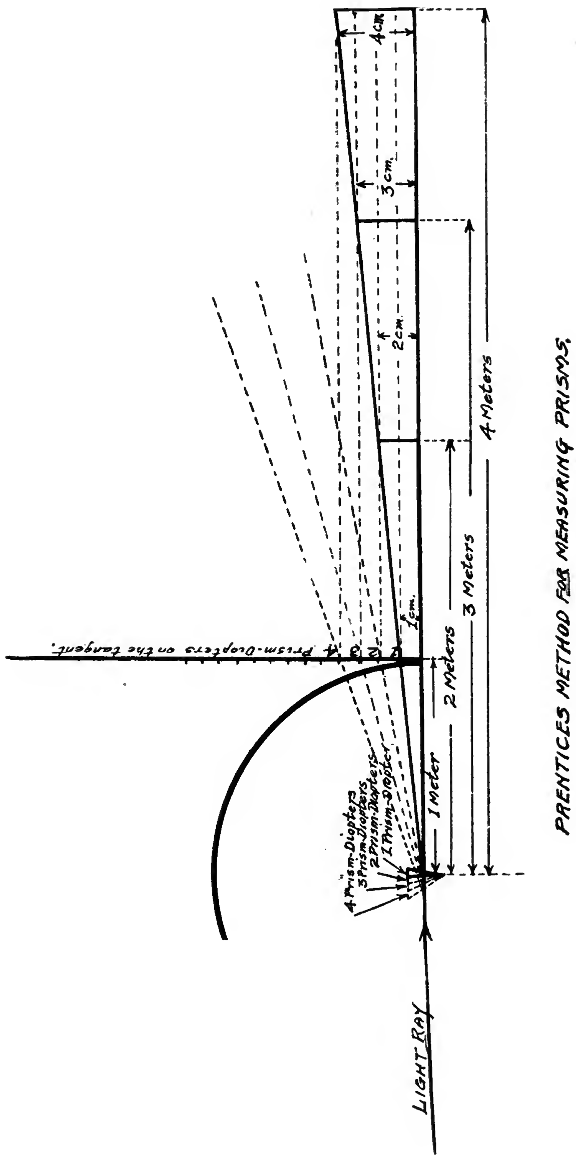
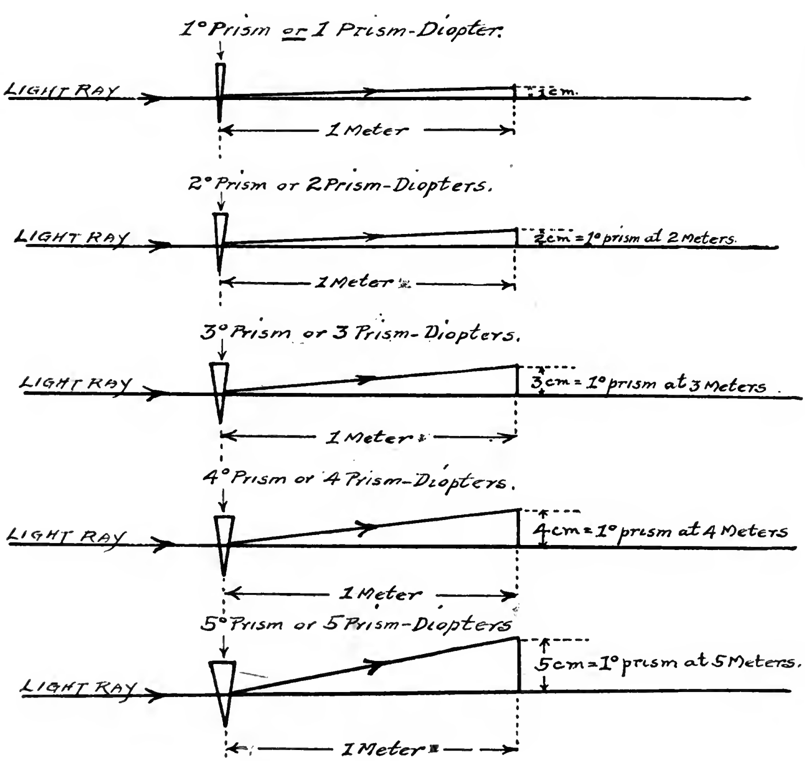

4 cm.
3 cm.
2 cm.
1 cm.
1 2 3 4 Prism-Diopters on the tangent.
4 Prism-Diopters
3 Prism-Diopters
2 Prism-Diopters
1 Prism-Diopter
1 Meter
2 Meters
3 Meters
4 Meters
LIGHT RAY
PRENTICES METHOD FOR MEASURING PRISMS.

Fig. 2

travels after leaving the prism. (See Fig. 2.) Thus a ray of light passing through a prism one meter distance and deflected one centimeter is said to pass through a one degree prism or a prism of one prism-diopter. Should a ray of light passing through a prism one meter distance be deflected two centimeters that prism then has twice the deflecting power of the unit prism and is therefore a two diopter prism.



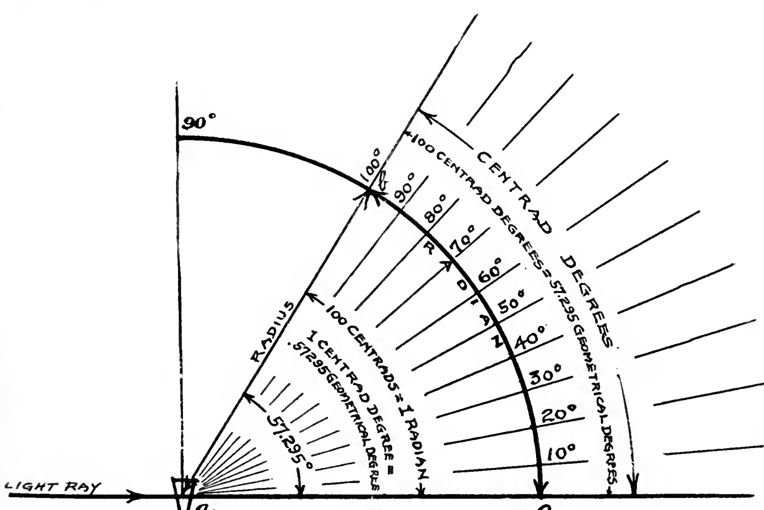
PRENTICE'S METHOD FURTHER ILLUSTRATED.

Fig. 3

If it deflects a ray of light three centimeters, four centimeters, five centimeters, etc., at one meter distance, it becomes then a three degree, four degree, five degree prism, or prism-diopter prism, etc. (See Fig. 3.)

Dennett's Method

The term *degree* as commonly used is intended to designate prism-diopter (P. D.) Hence, when speaking of a one degree, two degree or three degree prism we mean a prism of one, two, or three prism-diopters. However, to be more accurate, under the system of measurement known as the Dennett method, the *degree* really refers to a slightly different form of measurement. Its unit is known as the *centrad*, and, measured on the arc of a circle, is the one-hundredth (1/100) part of a radian (57.295 degrees), or 0.57295 degree. (See Fig. 4.)

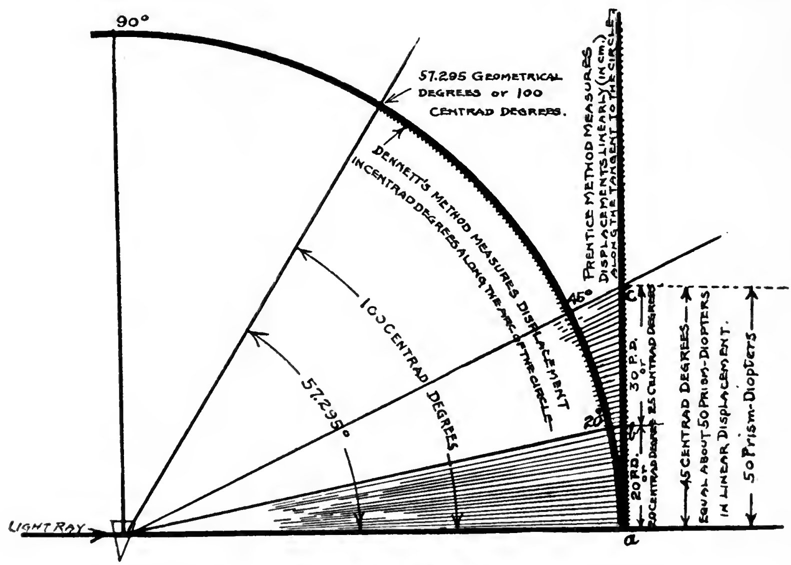


DENNETT'S METHOD.

Fig. 4

Prentice's Method

Under the prism-dioptry system, known as the Prentice method, the unit prism-diopter is measured along the tangent to that circle and represents, as already explained, one centimeter deviation for each meter distance. (See Figs. 2, 3 and 4a.) Up to twenty centrad degrees the *Dennett degree* or *centrad* and the *Prentice prism-diopter* are practically the same in linear measurement, after which in an accelerated progression the prism-diopter greatly outstrips the degree on the arc. (See Fig. 4a.) Within twenty degrees



COMPARING DENNETTS and PRENTICE'S METHODS.

Fig. 4 (a)

therefore one is quite accurate in using the terms *centrad*, *degree*, or *prism-diopter* interchangeably; beyond that, however, one might be expected to confine himself to the proper nomenclature.

Inasmuch as in ophthalmic prescription work, one seldom uses more than twenty units of prism power, the term *degree* seems to have become quite popular, in verbal usage at least. Written form, however, accepts the Greek symbol delta (Δ), equivalent to our letter "D," to represent prism-diopter, when desiring to express prism power in a given formula or prescription. As an historical fact, and for the sake of accuracy, it may be well to add that the term *degree* when first used was the geometrical degree (360 to the circle), measuring the angle formed by the two converging sides of the prism at their juncture, the apex. Thus a one, two or three degree prism was that one, whose angle at the apex measured one, two or three geometrical degrees. These *degrees* it will be observed do not correspond in angular value to the *degree* expressing *centrads* and have had a rather more or less indeterminate deviation value. (See Fig. 4.)

Influence of Prisms on the Eye

While a prism bends a ray of light towards its base, to the eye looking through it, that ray appears to have its source in the direction of the ray's deviation. (In Fig. 5 the ray

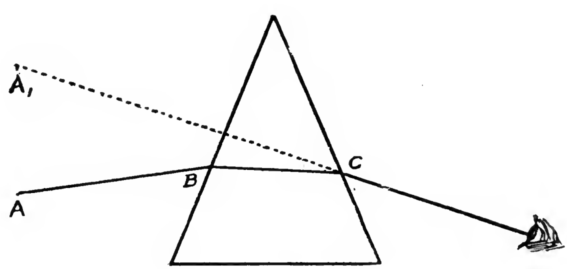


Fig. 5

A B appears to have its origin as A_1 C, or the point A seems displaced to the position A_1.) In connection with this we learn that an eye looking through a prism is impelled and

does turn towards the *apex* of the prism; that is, in the direction towards which objects in space seem to be displaced. The tendency for the eye to thus rotate at once suggests the utility of prisms for measuring the power of extrinsic eye muscles and for exercising these muscles when such becomes necessary. Before entering upon the practical application of prisms for muscle testing and exercising we shall first investigate or analyze the reason by which an eye is impelled to rotate, as though drawn by a magnet, when looking through a prism and always *in the direction of the apex.*

Why the Eye Rotates Towards Apex of Prism

Since the *fovea* upon the retina is the most sensitive portion affording the keenest and minutest visual appreciation of objects, the eye in seeking to observe or fix an object will intuitively turn so that the image shall fall directly upon the fovea. Thus in placing a prism before an eye that is fixing an object the deviation character of the prism will displace the image which had hitherto been on the fovea to another portion of the retina. The eye will then seek in the interest of keener vision to replace the image upon the fovea. This it can accomplish only *by rotating with the fovea towards the new position of the retinal image*, or in the direction of displacement which is that of the base of the prism. (See Fig. 6.) As the fovea which is at the *posterior* (back) *portion* of the eyeball turns in the direction of the base of the prism, the *anterior* (front) *portion* of the eyeball will necessarily turn in the opposite direction, which is towards the *apex* of the prism. This condition is inviolable and will be seen to operate as described in every case when the eye is subjected to prism influence, except when muscles are paralytic or otherwise incapable. Fig. 6 illustrates graphically what has been verbally set forth, showing also how increased prism power will on the same principle produce a correspondingly increased rotation of

the eyeball. Increased rotation due to increased prism power means greater nervous energy expended through the rotating muscles and hence the principle of muscular exercise by prisms.

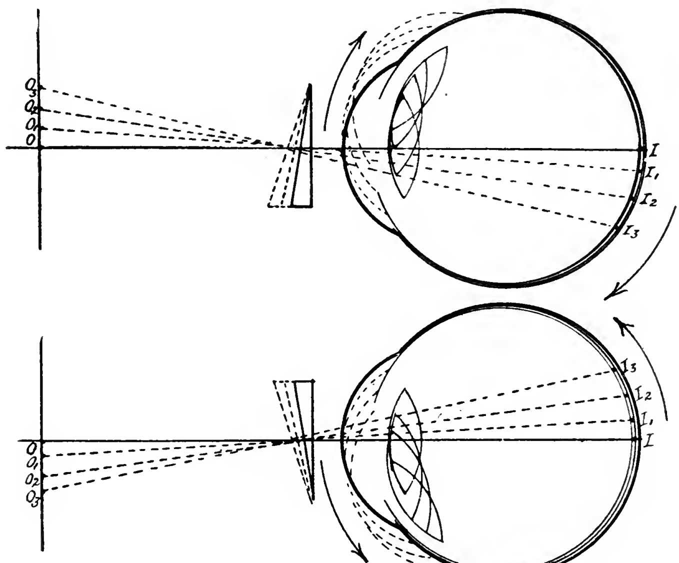


Fig. 6

Why Objects Appear Displaced Towards Apex of Prism

Since the mind interprets an object as situated in space directly in the line of vision whence its rays enter the eye (the law of projection, Fig. 5) it will readily be seen, if we refer to Fig. 6, why objects appear displaced towards the *apex* when looking through a prism. Thus the deflected rays from object O meeting the retina at I_1, I_2 and I_3 as corresponding prism power is placed before the eye, will, when projected back in the direction from which it entered the eye, establish the object apparently at O_1, O_2 and O_3

showing the apparent displacement always towards the *apex* of the prism.

Two facts then with respect to prisms that are fundamental and essential should be remembered:

1 *Prisms bend rays of light always towards their bases.*
2 *Objects viewed through a prism always appear displaced towards the apex and the eye in order to properly fix the apparently displaced object must rotate in the direction of the displacement, which is towards the apex of the prism.*

From this we learn the all important fact that, should we desire to make an eye turn in any direction by means of a prism, *we need but place the prism so that the apex will be in the direction in which it is desired that the eye be rotated.*

How to Set Prisms for Exercise

Thus, should we desire to exercise the internal muscles, which means that they shall be required to turn the eyes *inwardly*, we place prisms before the eyes with the *apices* over these muscles or *inward.* Should we desire to exercise or cause a pull on the temporal muscles we place the *apices* of the prisms over the external or outside muscles. In whatever direction we wish to rotate the eye *we merely set the apex of the prism in that direction.*

Express Prisms in Terms of Apex Instead of Base

It appears to the author that oculo-prism work will be grasped more readily if greater reference is made to the *apex** and less to the *base* of prisms. What makes the strongest impression upon the memory is that which has action associated with it. The *base* of the prism is always the passive side of it. It is the portion of the prism with which must be associated relaxation because it is always in the other direction—that of the *apex*,—in which the pulling is accomplished. It is quite natural to understand how

* It will be observed that Tscherning in his *Physiologic Optics* and Maddox in his *Ocular Muscles* refer to the prism always with reference to its *apex*.

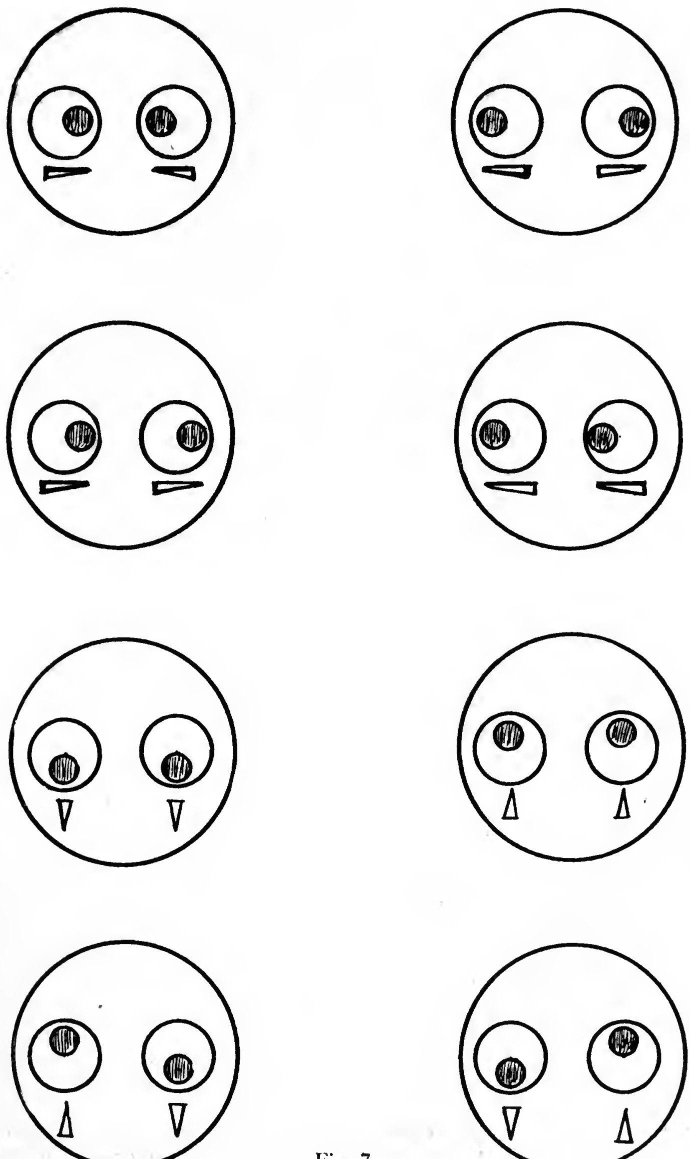


Fig. 7

prisms in the past,—used almost entirely as permanent corrections in lenses to permit weak muscles to relax into a position of ease and comfort,—were always designated in terms of their *bases* which induced the desired relaxation.

The future outlook, however, suggests the probability that the prism will henceforth be used more as an instrument in the hand of a professional operator than as a permanently prescribed vehicle in the lenses of the public. For that reason, that is, from the viewpoint of its utility for *muscle exercise*, it may be best for refractionists in the future to learn to work with the prism from the standpoint of its activating source—the *apex*. This will be found more logical and being the active and direct factor will eliminate undue confusion. Inasmuch as in prescription work it has been the custom to express prism power in terms of the base it will be necessary, until the custom changes, to follow the prevailing form by substituting for the *apex* the *base* equivalent, *i.e.*, in place of *apex in*, it shall be stated *base out*, and instead of *apex out*, it shall be expressed *base in*. The significance of the above conclusions is further realized when we refer to Fig. 7 showing several groups of eyes as variously influenced by prisms, each eye turning in the direction of the *apex* of the prism.

[To be continued]

The Comparative Value of Various Methods and Practices in Skiametry

being the

Dr. Ettles Memorial Lecture delivered in London, Eng.

Charles Sheard, Ph. D.

Synopsis

Factors Affecting Visual Acuity Tests: (1) Inaccuracy of Snellen type. (2) Difference in readability of different letters. (3) Age. (4) Pupillary diameter. (5) Retinal adaptation. (6) Change of acuity with the illumination. (7) Acuity and color.

Static Skiametry: (1) Ciliary relaxation. (2) Retinal sensitiveness to light. (3) Irregular and peripheral refraction. (4) Macular and non-macular refraction.

Dynamic Skiametry: Cross method—Sheard interpretation and method—Criticisms, favorable and unfavorable, of Cross theory—Accommodative lag—Use of dynamic skiametry as a single test—Writer's practice—Advantages of dynamic skiametry: (1) Small pupils. (2) Refraction in line of vision. (3) Astigmatic conditions. (4) Presbyopia. (5) Sub-normal accommodation.

Monocular and Binocular Amplitudes of Accommodation: Theoretical discussion—Practical considerations and procedures.

Illustrative Cases: (1) Sub-normal accommodation. (2) Simulated myopia. (3) Hyperopia with high esophoria.

Summary of points with reference to dynamic skiametry.

Introduction

CATHOLICITY of notions, breadth of view, ability to be unselfishly interested in the work of other men, and withal the possession of the virtue of Christian charity are vouchsafed to relatively few persons. Dr. William Ettles was such a man, for he had the true interests of the science, which was his life work, close at heart. The spirit of the search for the truth pervaded his whole being, and coupled with the desire for the knowledge of the truth was the desire and ability to impart of his findings to his fellow practitioners, irrespective of the narrow confines of schools and confines of doctrine. During these years with which I have been familiar with the literature on various phases of physio-

logical optics, I have had the pleasure of seeing the name of Dr. Ettles attached to many articles of much importance. We have all of us been made better men and better practitioners by virtue of his life and his work. And as we gather here together to pay tribute to our colleague and fellow-worker who has gone on before us, we do so with the full assurance that no man who has lived and labored as did Dr. Ettles shall have done so in vain.

Dr. Ettles was particularly interested in the science of retinoscopy, as many call it, and many articles came from his pen on this subject as well as on matters dealing with proper office and clinical arrangements and practices. It seems therefore to be appropriate that we should take as the subject of a lecture, bearing his name as a memorial, one which we may be sure would have aroused his keen interest and brought forth comment from his fertile brain were he with us. We shall, therefore, in that which follows, present to you some remarks upon the topic: *The Comparative Value of Various Methods and Practices in Skiametry.*

It is not our purpose to go into the details of the methods and practices of static skiametry (or retinoscopy), for it may be with propriety assumed that my hearers are familiar with its fundamental principles. However, in opening this discussion it may be well to briefly point out some of the factors affecting visual acuity in order to, in the first place, show the necessity of some objective methods of examination and to then proceed to outline some of the advantages and disadvantages of the method of static skiametry. We may then be permitted to briefly discuss the technique of the dynamic skiametric procedures, pointing out the benefits to be derived from its use as an office and clinical practice.

Factors Affecting Visual Acuity Tests

With respect to factors affecting visual acuity, let us briefly rehearse the more important. (1) The Snellen test types of our clinics and offices are but assumed standards which

are found to serve us rather conveniently in the practical work of ocular refraction. The acuity depends not only upon the quality of the dioptric apparatus but also upon that of the retina, of the optic nerve and of the brain. (2) It is a well-known fact that some letters of the same size and subtending as a whole the same visual angle are much more easily read than others. For if we take the ability to recognize the letter B at the five minute angle as standard or V = 1, we find that the average acuity required for the letter L, for example, of the same size and subtending the same visual angle is about V = 7/10. (3) Age affects the acuity for reasons which are obvious. In general there is in the healthy eye a slight but uniform decrease in acuity from the fortieth year on. (4) The influence of pupillary diameter upon visual acuity is quite marked; the optimum pupil corresponds to about 3 or 4 mm. diameter. Hence eyes having equality of functions and structure in all particulars and yet varying unduly in pupillary area will have quite appreciable acuity differences. (5) The condition of retinal adaptation plays a part in acuity conditions, for in general it is found that (a) for low intensities of illumination the visual acuity increases with darkness adaptation, (b) for average luminosities it remains the same whether the retina is adapted or not, and (c) for high intensities of illumination the acuity decreases with darkness adaptation. (6) All methods of observation and experimentation show conclusively that the visual acuity increases at first quite rapidly with small changes in the illumination but that finally a very large increase in luminosity is demanded in order to change the acuity by a small percentage. This point is of significance in the matter of test-card lighting. (7) Visual acuity increases and decreases more slowly under colored illuminations having short wavelengths than for the less refrangible radiations for any given variation in the objective luminous intensity. Also the acuity is greater in yellow light and decreases through red, green and blue.

Static Skiametry

We, therefore, appreciate from these facts the sources of error underlying visual acuity methods of determining errors of refraction and must admit the necessity of some objective methods which will determine the excess or deficit in power of the eye in a manner analogous to that in which we determine the focal power or powers of a lens by neutralization methods. Skiametry is an objective method of neutralizing the error of an eye. For, by means of a mirror we illuminate the retina; the retina in turn becomes the luminous object, and is at one of the conjugate foci of the ocular system and we are desirous of finding the other conjugate. If the second conjugate is at infinity we may arbitrarily bring this returning light to any point desired by using a lens of a power whose focal length is equal to that of the observation point from the eye examined. If the conjugation point to the retina should lie between the eye observed and the observer, no lenses being used, evidently a condition of myopia exists; whereas if the conjugate should lie back of the observer a condition of hyperopia, or of myopia of a lesser dioptric power than that represented by the observers' distance from the observed eye, is known to exist.

The theory of static skiametry is simple and straightforward and as has been stated involves fundamentally nothing more than Foucault's method of determining the focal length of a lens, and is simply an application to the eye of methods familiar to those conversant with physical optics. But skiametry is a part of the practice of physiological optics —and therein lies the rub, for we cannot pick up, turn and twist the eye to suit ourselves as the physicist can his lenses. And we have an instrument of "blood and water," with muscles and mechanisms for changing the power of the eye, we have diaphragms of varying size and we have very decided aberration effects. And withal, we have a human being as the possessor of these eyes, with all the frailties, whims and fancies of human kind. Therefore, we shall call attention at

this time to the fact that under ideal conditions, with proper relaxation of the patients' accommodation, proper positions of visual axis with respect to the line of observation and examination and accurate centering of optic media, perfect neutralization of skiametric motion should be possible: this method should therefore afford a means, par excellence, of determining objectively and hence, scientifically accurately, the patient's farpoint. But these ideal conditions rarely exist: there are certain possibilities of error in skiascopic tests which give rise to disagreements between such determinations and those made under subjective tests. We were rather severe in our criticisms of visual acuity tests as the unimpeachable standards and court of last resort in ocular refraction. With equal candor must we now turn and briefly enumerate and discuss some of the reasons why static skiametric tests may be inaccurate and incorrect and not give us a true measure of the ametropia of an eye. The element of infallibility, it is always to be remembered, does not attach to any one single method or test, hence a comparison of all ocular data and a modification in the light of the evidence furnished by all tests is demanded in the determination of the final binocular findings.

(1) *Ciliary Relaxation—Fixation definite but passive.* If the subject under test looks vaguely into space without the assistance of some definite and visible fixation point, his gaze is likely to be uncertain in both direction as well as in space location. The subject will invariably grope for some object at which to look, often the operator. To insure definiteness of fixation and to overcome this objection, the illuminated one hundred foot letter or letters may be used at twenty or more feet; if perchance this letter (or these letters) are not visible, the form of the illuminated chart as a whole or the frame in which it lies will generally be so. *The great criterion in static methods is relaxation.* Hence monocular fixation must be *definite* and *passive*. Monocular fixation must obtain, since any possible relations involving accommodation

and convergence in the act of binocular single vision are to be eliminated. Various schemes are possible in order to obtain passivity of gaze. One such device as used by the writer and, in so far as known to him, first advocated by him, consists in turning up in the lens battery of the optometer or introducing into the trial frame sufficient lens power to considerably overcorrect any initially discovered hyperopia when only working distance lenses are inserted. The procedure is to then slowly reduce lenticular power until the maximum plus power just before reversal occurs is reached. The writer is satisfied that higher degrees of hyperopia will often be disclosed under such a *modus operandi*. In myopia, of course, the procedure is to employ the minimum minus lens possible. Then, again, after making the monocular static retinoscopic findings we often find it of advantage to allow both eyes, wearing the monocular findings respectively, to passively fix; in this manner we determine the binocular static retinoscopic findings and often find that from a quarter to occasionally as high as a diopter additional convex lens power can be added to either or both eyes before reversal occurs. The reasons for this additional finding under binocular fixation for distance are well-known to you, for it is a matter of common knowledge in practice that one of the procedures in subjective testing should be to endeavor to add to both eyes as much plus lens power as possible after having obtained satisfactory monocular findings. Obviously such possibilities as spasm of accommodation, latency of hyperopia and interrelationships of accommodation and convergence may exist and modify very materially the subjective and objective monocular findings. There are those who believe that ciliary relaxation is induced by putting over the eye not being tested a strong fogging lens together with a four or five diopter prism, base in, both eyes being thus left open, *i.e.*, uncovered during the test. The writer does not feel that this is as good a procedure as to make separate monocular and then finally binocular static skiascopic findings.

(2) *Retinal Sensitiveness to Light.* Retinae unduly sensitive to light may cause in static retinoscopic methods a temporary irritation that will produce a spasm of the ciliary. Such reflex actions may be induced to relax by dimming the source of light used; this is very satisfactorily accomplished by use of the self-luminous instruments in which the luminosity may be controlled through a resistance. Perhaps some of you may object to the very unsatisfactory spot of light given by many self-luminous instruments because of the casting of the image of the filament in the form of an ellipse or the letter S and even at the best giving a poor source of illumination for accurate determination of astigmatism. But this feature has been made almost ideally perfect in the latest self-luminous retinoscope devised in America, and the diffused light of low intensity is an admirable arrangement for accurate skiascopic work.

Sometimes lacrymation is so excessive and photophobia so pronounced that the findings have to be obtained *ad interim*, allowing time for the eyes to readjust themselves. Such conditions are a trial to the examiner, since there is first a motion "against" and then a motion "with" or *vice versa* and he is left in some doubt as to the true refractive error. But he has first-hand information at any rate as to the character of his case: and that is oftentimes of the greatest assistance, for he knows what to look for and what he must guard against in his subjective findings.

(3) *Irregular and Peripheral Refraction.* Many retinoscopists are called but few are chosen. Many practitioners judge themselves to be skilled in the use of this most valuable refractive instrument, whereas as a matter of fact they fail to do two things which, paradoxically, become as one, namely: to disregard all peripheral conditions and to give heed strictly to the reflex or skiascopic movement in the visual zone. Irregularities, neutralization of shadows and even reversals of motion may occur in the peripheral regions in fairly large pupils due to aberration and other effects. These are at

times very confusing and annoying to even skilled operators. Often thin, colorless ribbons, approaching in form the band condition peculiar to astigmatism, may arise which are due to irregularities and reflections in or from various dioptric surfaces or media. These generally fail to prove out in subjective testings. We have seen many men of fair experience—in matter of time or service at least—considerably undercorrect hyperopia and overcorrect myopia from the standpoint of static retinoscopic findings.

The writer has made it a practice to work at about 26 inches and allow one diopter only for the working distance. No scientific reason, in the sense of a theoretical reason, can be assigned. We can only say that we do feel that hyperopia is too often undercorrected and myopia overcorrected and low hyperopia too often fitted with weak concave lenses. While we do not feel as though we could go as far as some ophthalmological writers do and declare that the retinoscopic findings made at one meter working distance without cycloplegics should have no allowance made for the working distance, we do feel that some such allowance should as a general rule be made by the retinoscopist and that its value should approximate a half diopter.

(4) *Macular and Non-Macular Refraction.* One of the chief sources of error in static skiascopy is the fact that most practitioners do not make the findings along the visual axis. In subjective findings the image of the letter fixed is formed at the fovea. In retinoscopy, without cycloplegics, the eye is deviated some degrees from the line of the examiner's observation, hence the reflex and shadow are concerned with parts of the retina not concerned with refraction along the visual axis. It is possible that, in many instances, the image from the operator's mirror may fall at or near the optic disc; this is evidenced by the character of the reflexes obtained and is to be avoided. To find the true *spherical* error by retinoscopic procedures, therefore, it is essential that the examination shall be along the visual axis, so that the fovea

may be the conjugate point in skiascopic work the same as it is in subjective testing. And again, if a high-powered lens is rotated about an axis, a cylindrical effect is introduced. The eye is of high dioptric power; the turning of the eye a few degrees such that the line of examination is oblique or makes an angle with the visual axis is sufficient to materially interfere with the correct finding of the amount and the axis of the astigmia, or again to introduce astigmatism when not present or to change a low amount of astigmatism with the rule to a corresponding amount against the rule. You must all have had illustrations of this; cases which gave, let us say, retinoscopically +0.25 ax. 180, when careful subjective tests gave +0.25 ax. 90. One of the chief inaccuracies, therefore, in static retinoscopic methods lies in our failure to commonly make our findings along the visual axis. This defect can be easily remedied, for Eberhardt, Armbruster and Herbin have devised schemes (which are essentially the same) consisting of parallel mirrors set at an angle of 45 degrees on a suitable bar, so arranged that the form of a distant letter may be reflected from one mirror into the second and thence into the eye. The eye to be examined may in this way passively fix a letter while the examiner makes his static skiascopic findings along the visual axis, thus affording himself greater accuracy in both spherical and cylindrical corrections and getting rid of spurious and annoying reflexes. The possibility of inaccuracy in findings is thus reduced to a minimum.

So we have to say that it is our belief that static retinoscopic findings when properly made, giving heed to the points especially which we have been discussing, do afford the most accurate determinations of the refractive excesses and deficiencies when the eyes are engaged in the general work of distance seeing. For vision which may be called distant seeing, to differentiate it from close work such as reading, involves a minimum of accommodation to see clearly and a minimum of convergence to see singly. There should be theoretically no accommodation and no convergence

demanded at distance. Practically speaking, however, a pair of eyes slightly hyperopic and slightly exophoric will be the best seeing and most keenly working binocular machine.

Dynamic Skiametry

But we have pointed out that visual acuity tests have their weaknesses, and we have discussed some of the inaccuracies which may creep into static retinoscopic methods. Both subjective and static retinoscopic findings are, however, solely for the purpose of correcting anomalies and errors of refraction, or in other words, putting the far-point of the eye in each and every meridian at infinity. They are used, then, to give keener distance vision, as in hyperopia, myopia and astigmatism, or to allay unnecessary ciliary action as in hyperopia, or to supply a deficit in myopia so that the function of accommodation will be presumably called into action to the normal amount at all points within the far-point. Subjective visual acuity tests and static retinoscopic tests do not concern themselves with accommodation—the act of seeing distinctly at points inside infinity, or convergence—the act of binocular single vision, nor do such methods concern themselves with the relationships between accommodation and convergence, or the derangement of one or the other, or again their mal-coördination. Static skiametry is exactly what its title says it is; if we wish to objectively investigate the amplitude of accommodation, the excesses or deficiencies of accommodation, or again find out how much assistance the eye would accept under any specified condition of relative accommodation and convergence, we must turn to dynamic skiametry. Static skiametry has to do with distance findings; these findings may or may not be satisfactory for reading purposes as, for example, in presbyopia; static skiametry makes no pretense at a solution of close-work ocular problems. Dynamic skiametry, on the other hand, is an objective method of finding out whether or not the static findings will serve

satisfactorily in near work. To my mind dynamic skiametry is useful, chiefly, if not in its entirety, in finding the assistance which the accommodation either needs or will accept under the conditions imposed by virtue of the point fixed and for which accurate accommodation is undertaken.

The dynamic skiametric method as devised by Cross in the early '80's consists in having the patient read letters or count dots on a fixation chart while the examiner takes note of the character of the reflex (shadow) in each eye, one eye after the other. The procedure as commonly adopted in this method is to initially obtain by static retinoscopy those refractive findings which put the eyes, monocularly, in an optical condition such that the retina and the distant point, presumably passively fixed, are conjugate points. The distance corrections are then inserted before the eyes under test and the patient is told to read aloud a series of letters indiscriminately arranged or count a number of fairly large dots upon a test card attached to the retinoscope. This test is a binocular one in general, since both eyes are involved, hence convergence and accommodation are both demanded in order that binocular single vision may ensue. While the subject under test is reading the letters or counting the dots the examiner takes note of the character of the reflex or shadow in each eye, one after the other. Should he find a *with* motion, using a plane mirror or the Cross form of dynamic skiascope, the practitioner then proceeds, according to the method generally advocated, to add such convex lenses as will give a slight overcorrection binocularly as evidenced by the *against* character of the skiascopically obtained shadows. Or again, the following method may be adopted: the person under test is instructed to fix a point on or *very* close to the examiner's skiascopic mirror; the operator chooses whatever distance he desires and then determines the lens quantities which will just produce a reversal of shadow. We believe that these statements cover, in essentials at least, the mechanical procedure, unless

we add to these remarks the further statement that, should an *against* motion be obtained with fixation and observation at any given point, concave lenses should be added until a neutral shadow is found in both eyes. The fixation point, when fixation and skiascopic observation are made at one and the same position, may be varied to suit the practitioner. Commonly chosen points vary from ten to twenty inches from the eyes under examination. This method, which we may designate as the simultaneous-fixation-observation procedure, may be modified as has been suggested by Cross and fixation may be demanded at any desired point through the medium of a suitable chart or test object, while the reversal of skiametric shadows is sought at another point. For example, fixation may be made at 26 inches and the reversal point sought and found at 40 inches. This procedure is analogous to that which may be used in myopic cases under static skiascopic methods in which the points or positions of skiametric reversal may be located. The writer rarely uses either of these static or dynamic determination of reversal point methods for the reason that measurements of distances are likely to be too inaccurate to be of value from an exact refractive standpoint. This measurement method of finding the skiascopic neutralizing lens quantity is, however, very rapid and satisfactory for obtaining the order and magnitude of the error in either static or dynamic procedures, particularly in cases where the reversal point is within a one meter distance. The "fixation-at-one-point and observation-at-another-point" method of operation in dynamic skiametry has been criticized by many on the basis that it is impossible for the patient to read the letters on the chart and still have an observational reversal point at another position. This criticism is unwarranted provided there is not instituted a change of lenses before the patient's eyes to bring the skiametric reversal to any specified point. For "ray values" have their equivalent lenticular counterparts. If fixation should be made at 20 inches, for example, and the operator

should find a neutral point at one meter (equivalent to 1D.) then, under the procedure as we shall outline it, we have evidence that +1 D. lenses are required in order that the positive range of relative accommodation, the negative range of relative accommodation and the convergence may be properly correlated. But more of this in that which follows.

Cross recommends the use of his own peculiar form of skiameter which carries a light frame attached to the mirror support in such a manner that one fixation card is slightly behind and the other slightly in advance of the operator's nodal point. The fundamental principle underlying this device is that when full correction has been approximated with fixation at the card more remote from the subject's eye, a quick change to the slightly nearer fixation object is made possible and that, if there is then a *reversal* of shadow, a correct refractive finding as to the needs of a pair of eyes *at the point fixed* has been found in order that the accommodative and convergence relations may be properly maintained. The writer of this treatise differs from Cross as to his notions of just what this dynamic test means and, therefore, in his *modus operandi*, for he uses the simple form of plane retinoscope with a small card attached thereto and printed in heavy-face eight to ten point type. In passing, let it be stated that the card which serves as the test object should be sufficiently illuminated; we carry out such tests in a room fairly well-lighted artificially.

In his presentation of the theory of dynamic skiametry Cross writes: "While the static method of practising skiametry is one where the ciliary muscle of an eye is at rest, the dynamic method is the exact reverse of this, and is made while the accommodation is exerting itself sufficiently to readily accept refractive assistance up to a point where its relation with convergence is interfered with. So in dynamic skiametry a call is made for a pronounced increase of the accommodation by having the patient read a series of test

letters placed on the observer's brow" (the writer then gives other methods), "then varying this tension as judgment teaches, and by being able to easily supply required artificial lens power, *the accommodation is reduced to its normal relationship with convergence.* And most eyes, no matter what the age of the patient may be, *will only surrender the accommodative excess* which has been required to maintain near-vision. The relationship between accommodation and convergence, if roughly stated, is found to be in about the proportion of one to three for the two eyes." The writer's interpretation of these statements of Cross is that he (Cross) believes that the accommodative excess will be surrendered only to the extent of the establishment of a normal "one to three" ratio between accommodation and convergence.

We are not much in accord with the theory of Cross as quoted or as amplified in his book. We are, however, in agreement with the statement that tests can be made to determine when the accommodation is reduced to its normal relationship point. But our procedure and interpretation are somewhat different. For we have the phenomenon of the relative range of accommodation to consider when the convergence remains fixed and constant. When fixation is demanded and obtained at any point a definite convergence is involved. Subjectively, we may use the Gardiner or Howe forms of optometers and proceed to find out how much convex lens power can be added before the test type, normal or taken as the standard, for the *distance of the test*, becomes blurred and unreadable. This determines the negative range of relative accommodation. We may well ask the question at this point: Is not dynamic skiametry, when practised with fixation and observation points identical, and convex lens power added (or concave lens power removed) until skiametric reversal occurs, simply and purely an objective method of determining the negative range of accommodation? We believe it is, and if so it is a most valuable asset in investigations upon ocular conditions. A

citation from Cross—which can be repeated by anyone in almost any case of hyperopia—supports this view. He writes: "Case I. Fixation, 40 inches; observation 39 inches. Shadow with the mirror. Can add plus 1 D. before reversal occurs. But with fixation and observation at sixteen inches, a total of plus 1.50 D. can be added before reversal takes place. Same result is obtained with fixation and observation at thirteen inches." These results are in accord with an affirmative answer to our question, for relative accommodation convergence curves show, except in rather rare cases, a decrease in the positive range (through concave lenses) and an increase (through convex lenses) of the relative amplitudes as the fixation and, therefore, the convergence are changed. The writer believes that a careful study of a few cases by both relative range of accommodation and convergence subjective methods and by dynamic skiametric tests will substantiate this explanation.

The question may, therefore, be very properly raised at this juncture: Is there any objective method of procedure whereby one can determine the lenticular assistance needed in binocular single vision at any given reading point such that the proper relations between positive and negative ranges of relative accommodation and the convergence may be met so as to establish normal or balanced conditions? We again answer in the affirmative and say that there should be placed before the eyes, for any given fixation and observation distances, the maximum convex or the minimum concave lenses which will just give a neutral shadow and that we should not proceed to the point of adding such lens quantities as will produce reversal. The distance binocular findings may be inserted previous to this test and they may be made the basis of further lenticular changes under this proposed system of dynamic skiametry until neutrality of shadow arises. To illustrate: We found in a certain case the following: static skiametry, O.U. +1.00 D.S.; dynamic skiametry, as advocated above, at 13 inches +2.00 D.S. and

for reversal +3.00 D.S. The positive range of relative accommodation at 13 inches was found to be 3 diopters and the negative 3 diopters. Such data show that the positive part of the relative accommodation in this case was abnormally taxed by the hyperopia present and that, by its alleviation to the extent of 2 D., a balanced condition between accommodation and convergence was established. As Donders stated, "The accommodation can be maintained only for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably large." The foregoing data show that such was not the case. We believe, therefore, that dynamic skiametry when properly practised will afford a quick and accurate method in general of finding that lenticular assistance needed at the reading point to re-establish normal relations between the positive range of accommodation, the negative range of accommodation and the convergence.

Accommodative Lag

Furthermore, we feel rather positive from a long series of tests by various modified methods of skiametric testing, that there is always a lag, skiametrically considered at least, of the accommodation behind the convergence. By this we mean that eyes practically emmetropic as far as any static or subjective tests could determine, possessed of plentiful amplitude of accommodation, fusion powers and reserves ample—in other words, as nearly physiologically perfect as could be found—have demonstrated to the writer the fact that small convex lens quantities are always accepted skiametrically, fixation and observation being in the same plane. These convex lens quantities usually remain constant, irrespective of the distance of the fixation point and amount, to practically half a diopter to three quarters of a diopter before neutrality of shadows is obtained. Another method of testing is to take an emmetropic pair of eyes and have them fix a very small letter on a quarter inch fixation card held on a

thin rod and to then determine the point of neutral shadow skiametrically. In such emmetropic eyes—or those which have been artificially rendered so, in so far as refractive errors are concerned, for some time—we have found that the neutral or reversal point is slightly farther from the patient's face than the fixation point, irrespective of the position of this point. We have designated this as a *normal lag of accommodation*. If this condition is universal and is not much affected by the nature of the error—and for some reasons we believe that it should not be and from other viewpoints we are not so certain—then we should expect all dynamic findings skiametrically to be slightly greater at close points in hyperopia and slightly less at close points in myopia as compared with the static skiascopic findings. We feel that this is an important point of variation in the technique and interpretation of the dynamic skiametric procedure as compared with the static method.

Such a test as the foregoing may be quickly made by putting a few small letters on a strip of card about a quarter-inch wide and attaching to a fixation stand or inserting in a small carrier attachable to the phorometer rod. With the nearest emmetropic and otherwise physiologically normal eyes under test the neutral point skiametrically may be found with various fixation points, such as 20, 13, 10, etc. inches. These values, converted into dioptric equivalents, represent the normal lag of accommodation behind fixation. The difference between the dioptric equivalent of the fixation distance and the dioptric value of the reversal point represents the lag of accommodation. Furthermore, it would appear that the only proper procedure in obtaining the true negative relative accommodation objectively is to determine experimentally by skiametry the lens quantity necessary for reversal and to subtract therefrom about a half diopter in cases of hyperopia and emmetropia and to add about a half diopter in cases of myopia. A sample set of data is the following:

Skiametric point of reversal (inches)	Dioptric value of reversal point	Patient's fixation point	Dioptric equivalent of fixation distance
15	2.6	13	3
12	3.3	10	4
10	4	8.5	4.7

This important observation does not appear to have been recorded by others and is of considerable significance if it proves to be correct in all particulars.

A corroborative proof of this claim may be obtained by a method to be discussed in another section of this paper having to do with an objective method of finding the amplitude of accommodation. If an operator, working with fixation and observation at one meter, adds lens quantity sufficient to produce neutral shadows at one meter, and then advances both observational and fixation points to thirteen inches, for example, demanding thereby three diopters of accommodation, then it will generally be found, either by a monocular or binocular test, that the movement of the shadow will be "with" (using the plane mirror) and that the fixation point must be kept constantly slightly inside of the skiametric observation point in order to obtain a neutral shadow. There is, therefore, evidently a physiologic lag or relaxation of the accommodation amounting to about half a diopter at 13 inches. We are not prepared to say that this lag does not change with the distance of fixation. In fact we believe that it increases at a slow rate with increase of convergence, probably changing from about a quarter to a half a diopter at one meter to three-quarters to one diopter at eight inches.

The most animated discussions have arisen as to whether or not the dynamic skiametric findings can be worn for distant use. In other words, the claim is made by some

that the dynamic findings indicate the lenticular assistance really (or ultimately) demanded by a pair of eyes and that this method operates (from the accommodative strain rather than the total relaxation of strain method of attack) to the same purpose as does a cycloplegic—namely, the determination of the full refractive demands. Hence the two methods, although radically different in procedure and in action, look toward the same sort of an indicated answer. The static findings without the use of cycloplegics or without careful fogging and the dynamic findings at near-points constitute the two extreme sets of findings between which the final prescription is to be determined upon by reason of other dynamic ocular tests at distant and near-points in particular. Other investigators claim that the findings as made by dynamic skiametry are those suitable for proper correlation of accommodation and convergence at the point fixed. They claim that the method affords a reading correction only. From a strictly scientific basis the writer believes that the latter view is, in general, the only one which can be substantiated. Hence, if a practitioner prescribes under all conditions that which leaves the visual acuity at or nearly normal, then no dynamic methods will be of any service to him. The static findings taken in conjunction with the dynamic objective and subjective tests will lead to the accumulation of that data from which the practitioner, in the light of his training, his experience and his scientific study, can formulate those lens prescriptions which will serve the real demands of the ocular regime and not simply cater to **V**=20/20 acuity tests. The question, "Would you prescribe from dynamic skiametric findings?", we would emphatically answer in the negative and say that we would prescribe from the results of no particular method but from the analyzed results of all the methods and data obtained.

In his own practice the writer uses dynamic skiametry, as a general rule, with observation and fixation at the point selected by the person under test as being the usual reading or

working distance point, and then proceeds to determine the lens quantities necessary to produce neutrality of shadows. This gives, as he interprets his findings, some indication of the accommodative assistance demanded at this point under the conditions of convergence—*i.e.*, whether the convergence necessary to binocular single vision be accommodative, fusional or a combination—which actually exist, without any information as to the results indicating monocular or binocular findings per se. Since, in addition, he believes that there is a normal lag of accommodation of about half a diopter on the average, this amount must be subtracted from the findings in hyperopia and added to the findings in myopia. If these findings are comparable with the static skiametric findings, then he is justified in the conclusion that static and dynamic findings are in agreement and that the function of accommodation is adequately served, that there is little latent error or spasm of accommodation, and so forth. For instance, if static skiascopy gave O.U. +1.25 D.S. and the dynamic methods for neutral shadows at 13 inches gave O.U. +1.50 D.S. to +1.75 D.S., this would be accepted as fair evidence of the probability that O.U. +1.25 D.S. or thereabouts would adequately serve these eyes. But if the dynamic findings were in radical disagreement with the static skiascopic data, then a condition of presbyopia, subnormal accommodation, latent hyperopia, spasm of accommodation or latent convergent squint might be suspected. For example, if static skiametry gave O.U. +1.25 D.S. and the dynamic findings gave O.U. +3.00 D.S. for neutral conditions at 14 inches, there would be suspected one of the conditions just cited and the operator would proceed to carefully investigate the case.

There may be and doubtless are ocular conditions in which dynamic skiametry fails to give data of much value. In high anisometropia, for example, it may happen that one eye will carry on the function of vision at the reading point, the vision in the other eye being suppressed and not function-

ing, hence dynamic findings on the fixing eye would be of value but of no significance with respect to the non-fixing eye. Such a condition is likely to arise when one eye is hyperopic and the other myopic. But again, in a case of anisometropia in which both eyes are hyperopic but one much more so than its mate, the act of binocular single vision may be enforced and accommodative action take place in each eye to the same extent. Then the dynamic findings on these eyes will be equally valuable in the determination of the lenticular assistance that each eye needs at the point of fixation.

As a result of experience, the writer generally obtains the static skiametric findings first, knowing that thereby he has found a correction, to the first order of approximation to say the least, that will place the eyes in as nearly a normal condition statically as possible. He then leaves in temporarily the spherical elements determined upon, in addition to the +1 D.S. used for the working distance skiascopically, and then has the patient fix a set of small letters on the mirror held at the patient's usual reading distance. This affords a rapid method of finding neutrality of shadows at this distance because, in the majority of cases, it is found that neutral shadows will be obtained almost immediately; if not, increase or decrease of lens quantities can be quickly made to effect neutral conditions. Cylindrical correcting lenses are removed in the dynamic determinations for reasons to be stated in succeeding paragraphs. In myopia we may proceed in the same manner and quite frequently do, but as often we start with no lens quantities before the eyes, using fixation and observation at the same distance, and add concave (minus) lenses until neutral shadows are obtained.

Since the majority of refractive cases are those involving hyperopia and since the greater portion of such cases evidence about the same amount of error in each eye and develop, under test, equal accommodative ranges and amplitudes and, furthermore, since the vertical imbalances

per se are generally not of sufficient amount to interfere with the function of binocular single vision, it follows that dynamic skiametry is a valuable tool in the hands of those practitioners who will take the time to think upon these matters and put them intelligently into practice.

Some Advantages of Dynamic Skiametry

Small Pupils. Large pupils may give inaccuracies in static skiametric work unless the refraction in the line of sight is carefully adhered to and observed. Smaller pupils are therefore preferable since there is a riddance of irregular refraction and spherical aberration in the peripheral zones. Hence, with accommodation and convergence at close points, together with the added stimulus of retinal illumination, the dynamic skiametric examinations quite frequently afford definiteness as to the principal refractive errors, eliminate the peripheral refraction and disclose the refraction in the line of vision.

Refraction in the Line of Vision. In our discussion of static skiametry reference was made to the fact that scissors movements and false conclusions as to astigmatic conditions might easily arise because of the fact that the eye under examination is not refracted in the direct line of sight. Various devices for obviating this trouble were pointed out. Dynamic skiametry permits of macular refraction without the use of any auxiliary device. We desire to again point out that errors may arise in skiametric work when the examination is made at a bad angle between observing and observed eyes. Dynamic skiametry, with its refraction along the visual axis, or static skiametry with the use of the macular reflectoscope, enables one to avoid these defects and to be positive of their physiological existence when they do occur.

Astigmatic Conditions. Irrespective of our opinions as to the correctness or incorrectness of the spherical elements determined by dynamic skiametry, it is to be admitted that

this method affords an excellent and rather accurate method of determining the amount of astigmatism. Where small amounts of astigmatism are uncertain by static methods it is generally true that they are discoverable by dynamic skiametry. And surely quarter diopters of astigmatism are worthy of attention and ought to be corrected as a general procedure if actually present and omitted if not truly present. When the amounts and the axes of the astigmia do not agree with the static or subjective findings there are then presented those differences in ocular data which enable the practitioner to ultimately find the real errors.

We are all aware of the rather pronounced differences met with in the data obtained subjectively, skiametrically and ophthalmometrically, upon the condition of astigmatism of an eye. Many physical and physiological reasons can be given to show why the ophthalmometric measurements, which give data upon the cornea only, should not indicate conditions of astigmatism in agreement with subjective and retinoscopic findings. And subjective and skiascopic findings may differ for various reasons (vide Sheard: *Physiological Optics*). The variations of amounts of astigmia can be accounted for more easily than variations in the apparent positions of the principal axes. Cases arise in which static skiascopic and subjective tests, conducted at twenty or more feet, disclose the axis of astigmatism at 90°, for example, when the ophthalmometer shows the axes at slightly oblique positions, such as 80° or 100°. Furthermore, it often occurs that ophthalmometrically determined axes agree better with dynamic skiametric findings than with the monocular determinations obtained with either static, skiascopic or subjective methods.

E. S. McClelland, M. D., in a recent article, calls attention to the fact, as he believes it to be, that "The dynamic method of retinoscopy is the only satisfactory one for the correction of hyperopic astigmatism in children, because it eliminates the confusing and unimportant shadows of exaggerated

astigmatism and other peripheral defects exposed by a fully dilated pupil, and also because it corrects an accommodated eye and not a relaxed one. Two things are of utmost importance in the correction of variable or hyperopic astigmatism in children, viz., a concentrated light of not less than eighty candle-power properly arranged and the eye to be corrected focussed for a meter's distance."

Presbyopia. Cross says of the use of dynamic skiametry in presbyopia: "Presbyopia is the one, so-called, 'easy' ocular condition that is often the most difficult of satisfactory correction, for the reason that occupation, illumination, habit, pupillary distance and innervation, or bodily vigor, are all factors to be reckoned with. Then, if combined with this the ignorance and stupidity of many patients in answering questions is taken into consideration, it is easy to see why changes in reading glasses are so frequent. Up to the time of the development of the dynamic method of practising skiametry there was no known method of estimating presbyopia in an objective manner. All static methods, whether with or without cycloplegics, are solely for determining the refractive condition of an eye when its muscles are in a state of complete relaxation, therefore the static method gives no definite aid in presbyopia whatsoever. Dynamic skiametry supplies the refractionist with a method that often proves of the very greatest aid in mastering a troublesome case, as it enables the eyes to be studied at all points, near as well as distant, this study being directed toward steadiness of convergence and accommodation, both of which can be detected through the use of a skiascope and lenses."

The practitioner is also given a method of objectively determining whether or not the accommodative need is the same in each of the two eyes tested. There is no reason for believing that there is an equality of accommodative amplitude of both eyes unless various tests show that such is the case. If the amplitudes of accommodation are equal, then

the refractive assistance demanded as the fixation point is advanced closer and closer to the eyes should increase identically the same for both eyes; if the amplitudes are unequal, then the skiametric findings at closer points should show a greater lenticular assistance demanded by the weaker eye. The data afforded by such tests give us information of much value in the fitting of a pair of presbyopic eyes.

Furthermore, it is always necessary to allow a portion—say one-half—of the accommodation to be kept in reserve and the other portion to be actually or actively used in close work. But the question is: How much in reserve and how much at work? Evidently each pair of eyes is a law unto itself. Other questions which must be answered before a satisfactory reply is forthcoming to this query are: Is there exophoria, or esophoria, or orthophoria (using the notation commonly employed in such connection) at the reading point? Are the fusion reserves adequate? As a result of additional investigations on the convergence relations there may come a reasonably scientific answer as to the amount of presbyopic corrections. But the test by dynamic skiametry quickly and accurately indicates the lenticular assistance needed in presbyopia.

Subnormal Accommodation. Dynamic skiametry is one of the most useful of all methods for determining conditions of subnormal accommodation. Such subnormal accommodation may be variously classed as (1) insufficiency of accommodation, (2) difficult or ill-sustained accommodation, (3) inertia of accommodation, (4) inequality of accommodation and (5) excessive accommodation.

Monocular and Binocular Amplitudes of Accommodation

The principles and modus operandi of dynamic skiametry may be employed to test the monocular and binocular amplitudes of accommodation. Some few years ago the writer devised this method and believes it to be original with him: at least he has never found it recorded nor seen it

practised prior to his own conception of the procedure. It is extremely simple of operation and in technique, and yet forms an *objective* method, as opposed to a subjective procedure. In brief, the method is as follows:—

The person under test is given a vertical line of type printed in about 12 point caps upon a card about one-quarter inch wide and fastened to some simple and convenient holder of about the same width. Or a single line ruled on a card or a pencil will serve quite satisfactorily as a fixation object, but there is not the incentive to full accommodation as when reading is demanded. The full monocular distance finding, affording as nearly **V** = 20/20 as possible, is inserted before the eye to be tested. The patient is then given the test-object—which he holds initially at about 13 inches—and is told to read the letters or make the attempt to do so. Or the operator may hold the test-object in one hand and approach it toward the patient. In general we have the patient hold the card slightly to the nasal side during the examination of either eye while we proceed to examine skiametrically from the temporal side and as close to the visual line as possible.

In ideal conditions the retina and the object viewed should be exactly conjugate points. This will obtain if the exact or requisite number of diopters of accommodation and fractions thereof are supplied. Hence, skiascopically, if this condition were to hold then the skiametric shadow would be neutral—observation and fixation points being the same—as the mirror is approached toward the eye. But if the object were to be slowly advanced toward the eye, the observation point, *i.e.*, the operator, remaining fixed in position, an against motion would arise, while if the test-object were to be moved back of the observer's mirror a with motion would occur. By then moving or having the patient move the test-object nearer the eye the actual near point will be found as soon as the retinoscopic mirror has to be operated in a plane back of the fixation point in order to obtain a neutral shadow.

These are ideal conditions in that we are assuming the presence of a true or artificially produced emmetropia and a perfectly innervated and functioning ciliary and lenticular action and that there is no lag of accommodation behind the convergence. In short, we are here rehearsing ideal and physically perfect conditions.

In general, we find that when the patient, wearing the full distance correction, reads monocularly the letters, there is a "with" or hyperopic motion—using the plane mirror—indicating that the point conjugate to the retina in an eye optically statically perfect is not at the position of the object viewed but at a point somewhat behind that point, *i.e.*, farther from the eye. Three valuable tests may be made. *First:* with monocular fixation and observation skiametrically at any point desired, the operator can find that convex lens power which must be added in order that the monocular accommodative demands, in the interest of conjugacy of retina and object viewed, may be met. This would be indicated by the additional lens power needed to give a neutral retinoscopic reflex. Suppose that +1 D.S. is thus demanded when both fixation and observation points are at thirteen inches: our interpretation would be that objectively an assistance to the accommodation over and above the assistance (or burden and tax in cases of overcorrected myopia) afforded by the static findings given the eye is required to relieve the accommodation of an extra burden. Notice that we specify minimum amount of additional lens power to produce neutralization skiascopically; more assistance might be and generally would be accepted under the method of procedure we have disclosed. *Second:* observation may be kept constant at any distance specified and the test-object drawn closer to the eye until a neutral shadow is obtained. For example, in a certain case the distance from the test-object to the observed eye is 10 inches and the distance between the skiametric mirror and the observed eye is 13 inches at which point a neutral shadow condition

holds: we should conclude that the accommodation actually available at ten inches is sufficient only for optical conjugacy at thirteen inches, hence indicating the need of a diopter of lenticular assistance. We must, however, bear in mind the probable physiological lag of accommodation which amounts, in the average case, to about one-half diopter. *Third:* by approaching the object closer and closer to the eye a point will finally be found such that no nearer approach of the test-object to the eye will change the neutral condition of reflex as skiascopically observed at the closest point to the eye at which a neutral shadow is obtained.

In testing, therefore, for the near point objectively we proceed as follows: The patient draws the test-object as near the eye as will still permit of its reading. To the observer at thirteen inches the skiascopic reflex will show an against or myopic condition indicating that he is outside of the optical ocular far point dynamically considered. The operator then moves forward until he obtains the neutral shadow position. The test-object is then to be carried still closer to the eye (blurred image as reported by the persons under test makes no difference) and the nearest point of neutral shadow found and measured. This gives the apparent near point under whatever ocular conditions the test is made (ordinarily when wearing the distance correction) and from it the range and amplitude of accommodation are readily determined. You will find some twenty pages of the author's *Dynamic Skiametry* devoted to this topic.

Illustrative Cases

Case A. *Subnormal Accommodation.* Mr. S. Aged 22. Static skiametric findings O.U. +0.62 cyl. ax. 90. Subjectively, same findings, V = 20/20. Under homatropine the findings were the same. Dynamic skiametry gave O.U. +1.50 D.S. ⊃ +0.62 cyl. ax. 90, with fixation and observation at 13 inches, to produce neutral shadows. This finding evidences an accommodative need of about one

diopter. Other tests on the amplitude of accommodation showed about 5 D. as a maximum. Patient complained of inability to engage in close work for any length of time. Ophthalmoscopic examination showed choroiditis in one eye and incipient conditions of chorio-retinitis in the other. Wassermann test positive: hence the probable seat of the abnormal accommodation was disclosed.

Case B. *Simulated Myopia.* Young lady, aged 23 years. Complained of frontal headaches, eye-burn, photophobia and the usual train of accommodative strain symptoms. Static skiascopic tests showed O.U. —0.50 D.S. Dynamic skiametry with observation and fixation at 15 inches, gave O.U. +0.50 D.S. for neutralization and +1.25 D.S. for reversal of shadow. Subjective binocular tests showed that O.U. —0.25 D.S. gave normal acuity and that O.U. +0.50 D.S. reduced it to not better than 7/10. The tonicity tests gave 2^{Δ} of esophoria and the accommodative convergence test evidenced 7^{Δ} of esophoria. These latter investigations were made without any lenses before the patient's eyes. We gave O.U. +0.50 D.S. which relieved the symptoms and after a few weeks' time gave practically normal acuity as well as comfort.

Case C. *Hyperopia with High Esophoria.* A young man, a chemist, who had suffered great ocular discomfort for years, presented himself and gave an interesting history of all kinds of ocular treatment. The observations on this case covered some two or three years, hence must be abbreviated in the report given here. The initial examination showed, using static skiascopy, O.U. +1.00 D.S. $\subset$ +0.50 cyl. ax. 90. Dynamic skiametry showed that +2.50 D.S. $\subset$ +0.50 cyl. ax. 90 gave neutral shadows at 13 inches. Without correction of any kind, the tonicity tests evidenced 10^{Δ} of esophoria and the accommodative convergence measurements some 13^{Δ} of esophoria. Subjectively, O.U. +1.25, D.S. $\subset$ +0.50 cyl. ax. 90 in the first examination did not give better than 8/10. We gave this young man O.U. +1.37

D.S. ⊃ +0.50 ax. 90 for constant wear. He became accustomed in a short time to the blurring caused by these glasses. We prescribed for him a year and a half later the full dynamic skiametric findings. These he wears with comfort and efficiency in his work but with an acuity not quite equal to 8/10. The criterion of normal visual acuity is a poor one in many cases, especially in conditions which are similar to the one we have just described.

Summary on Dynamic Skiametry

In closing this paper we are giving a summary of some points relative to dynamic skiametry and its service in ocular refraction.

(1) Data of value accrue to the practitioner through investigations by dynamic skiametry in which tests upon the coördination of convergence and accommodation, or simply upon the accommodative needs, to the enhancement of ocular comfort and economy while engaged in reading and other close work, are made possible objectively. The fact that static and dynamic results are not in agreement furnishes a basis for the determination of the proper assistance to be furnished in the interests of the dynamic functionings of the accommodative mechanism and furthermore, enables the operator to inhibit excessive innervation, relieve weaknesses or to economically draw upon functions which are in strength to the relief of those which are in weakness through the medium of the lenses which are prescribed.

(2) Dynamic skiametry *per se* is to be considered as an objective method of determining the negative relative accommodation, when observation and fixation are made at the same point and the lens quantities changed until reversal occurs.

(3) Dynamic skiametric findings taken at the reading point indicate increased convex lens corrections as compared with the static skiascopic and subjective acuity findings when presbyopia, subnormal accommodation or latent hyperopic

conditions exist. Such findings indicate the need of lenticular assistance in near work; also, when fusion dissociation tests at thirteen inches (or other point near the eyes) show the existence of an overconvergence associated with the accommodation in cases where little if any refractive errors or muscular imbalances exist at distance.

(4) The dynamic skiametric findings in myopia generally indicate lesser concave lens findings at the reading point than at twenty feet, because the deficiency in convergence, or exophoria, usually associated with myopia, is supplied by the fusional convergence, since the decreased accommodative demands in such cases elicit a corresponding decrease in the convergence associated with accommodation. It is probable, therefore, in cases of myopia in which fixation and observation points are outside of the patient's far point, that dynamic skiametry will indicate findings in fair agreement with those which would statically result if the patient's far point were to be left at the point at which observations are made. If such results accrue, it is evidence that full distance corrections should not be ordinarily prescribed for general use and especially for close work, since a too radical readjustment of the relations between accommodative convergence, fusional convergence and the accommodative act itself is not desirable. The history of the case, the symptoms of which complaint is made, the previous ocular corrections worn, or the absence of any previous refractive attention, must aid the practitioner in the judgment which he forms and prescriptions which he finally gives. In cases where the reserve fusional convergence is extremely weak or heavily overtaxed, it may happen that this deficiency in convergence will be supplied by additional accommodative convergence through an over-stimulation of accommodation, thereby indicating to the dynamic skiametrist as great, or greater, concave lens corrections at near as at distance. The demand for binocular single vision is met by increased accommodative convergence through the medium of accommodation. Or, again, cases

may arise in which greater degrees of myopia are indicated at the reading point as compared with the data furnished by the static findings. In such cases there is invariably a pronounced functional exophoria or, again, a condition of affairs in which this marked divergence is coupled with an accommodative mechanism in which less than one diopter of innervation accomplishes the act of one diopter of accommodative change.

(5) The dynamic skiametric findings, in which hyperopic conditions (*i.e.*, accommodative demands) are apparently found existent at near points, while static methods evidence low-valued myopic conditions at distance, demand careful investigation. Such findings are commonly found to exist in connection with spasms of accommodation and in cases in which there is an overstimulation of the interni by virtue of the convergence associated with the innervation delivered in the interests of accommodation, indicating esophoric conditions at the reading point.

(6) All skiametric and subjective findings should and must be supplemented by tests upon the amplitude of accommodation, the reserve convergence and investigations upon the convergence associated with the accommodation, while fusional convergence is passive, at the normal reading and near-work point. Such tests enable the practitioner to correctly analyze his case and to know why and in the interests of what function or functions his final prescription is to be given.

Abstracts and Reviews

Practical Considerations in Refraction

T. M. Li

AFTER giving a summary of the indications for refraction, Li gives a report on several of his interesting cases, to prove that there are many factors that must be considered if the patient is to secure relief from his symptoms. His experience convinces him of the necessity for thorough cycloplegia in the great majority of cases, and also an accurate determination of any muscle imbalance before prescribing correcting lenses.

Li has examined a large number of Chinese students. He does not give the number, but of those having errors of refraction, he found 53% with myopia, 36% with hyperopia, and 11% with mixed astigmatism. He states that "the high percentage of myopia found among Chinese students may be due to the peculiar construction of the Chinese characters and the close application necessary in learning how to read and write them.

"Reading the characters does not tax the eye so much as writing them. In China, to be able to write well is quite essential in one's education, which is judged largely by one's penmanship. In order to be able to write well every dot, stroke, and turn, made by the pen must be carefully manipulated and observed. One has to put in long years of diligent practice to acquire this art. In former days, as it is to a great extent nowadays, a student was considered disrespectful if he wore glasses in the presence of his teacher. In the different ministries of today, when an inferior goes to interview his superior, he has to approach him without glasses, according to usual custom and good manners. Poor

hygienic surroundings, usually found in a Chinese classroom, such as poor light, lack of fresh air and proper physical exercises, faulty position and long hours of study are also important factors in the possible production of myopia."

(Abstracted from the *National Medical Journal, China*, Vol. 6, page 108, 1920; this abstract appearing in the *American Journal of Ophthalmology* Vol. 4, p. 68, 1921.)

How to Use the Ophthalmometric Findings

F. D. Jackson, Norfolk, Va.

IF the cornea were the only refracting surface of the eye, the exact cylinder indicated by the ophthalmometer would be used invariably, with a possible modification due to the fact that the lens is not applied directly to the eye, while the measurements are made at its surface; or, if astigmatism were found only in the cornea, and not modified by any other refracting element of the eye, a careful measurement of the cornea would be the only thing necessary to insure an exact correction of the total astigmatism.

The fact that there exists astigmatism elsewhere than in the cornea is demonstrated by the fact that some eyes, having no corneal astigmatism, need correcting cylinders, as our other tests prove; and again, some eyes, having corneal astigmatism, do not require cylinders.

Ignoring the negligible action of the inner surface of the cornea, we have two refracting surfaces whose action is important to our consideration at this time, viz., the anterior and posterior surfaces of the crystalline lens. The lens of the eye is situated similarly to the segment of a Kryptok lens; both are of high power in air, but when imbedded in a medium of slightly lower refractive index, the effective dioptric value of either is limited to its excess in refractive index over its surrounding medium. This reduces the effective power of the crystalline lens to about one-fifth or one-sixth of what it would be if it were surrounded by air

instead of being imbedded in the aqueous and vitreous humors.

One or both of these refracting surfaces of the lens is, then, the modifying factor in our astigmatic correction, so that in correcting or neutralizing the total astigmatism of the eye, we must take both the internal or lenticular astigmatism and the corneal astigmatism into account.

Data for Final Correction

It might seem that this rather discounts the value of the ophthalmometer; but not so, for I maintain that the ophthalmometer gives us data from which the final astigmatic correction can be predicted within a quarter diopter, in the great majority of our cases, this majority being found under two diopters of astigmatism. Higher amounts than this will accept a nearer approach to the actual ophthalmometer readings, as the modifying effects of the internal astigmatism is proportionately less.

Having taken accurate ophthalmometer readings, in what way are they to be modified? Can a system or rule be applied to these data after we have them?

To answer this I will give my own rule or system, which I have verified by over 10 years of observation and practice since I adopted it, being satisfied that it might be called a rule only after numerous comparisons and check tests as to accuracy of results.

A sliding scale of deduction from the ophthalmometer readings follows: For ages up to about 20, deduct 1 D. with the rule from the corneal astigmatism; from 20 to about 35, deduct ¾ D. with the rule; from 35 up, deduct ½ D. with the rule. In mentioning these ages I use the word "about," as there can be no absolutely sharp demarcation from one amount to another at exactly a certain year.

For purposes of illustration, let us take three typical patients, designating them as Patient A, aged 17, Patient B, aged 25; Patient C, aged 40. Let us also agree that in

performing the refraction we will adhere to the accepted method of using minus cylinders in the trial frame.

For the first illustration, we find the ophthalmometer shows exactly 1 D. of corneal astigmatism with the rule, which of itself would be correctible with a minus 1 D. cylinder, axis 0, or a plus 1 D. cylinder, axis 90; this being the corneal finding in all three patients. If there were no other astigmatism than that of the cornea, these patients would be fitted with the mentioned 1 D. cylinder with the rule, and that part of the task would be finished. The fact that the ophthalmometer does not supply the answer by pulling a handle, adding machine-fashion, is rather disappointing to many would-be refractionists; but it is still a fact that the ophthalmometer does supply the exact data from which, with the application of that rare commodity, brains, the answer may be easily found.

Applying the rule given above, we deduct in the case of Patient A, 1 D. with the rule, from the corneal finding of 1 D. with the rule, and the answer is no cylinder at all; for Patient B, the deduction to be made is ¾ D., and the answer is ¼ D. cylinder with the rule; for Patient C, deduct ½ D. with the rule, and the answer is ½ D. cylinder with the rule.

For the second illustration, we find in all three cases no corneal astigmatism whatever; the cornea is perfectly spherical. In the case of Patient A, we deduct 1 D. cylinder with the rule from nothing, and the answer is, 1 D. cylinder against the rule, *i.e.*, minus 1 D. cylinder, axis 90, or plus 1 D. cylinder, axis 0; for Patient B, we deduct ¾ D. cylinder with the rule from nothing, and the answer is ¾ D. cylinder, against the rule, and in the same manner the answer for Patient C is ½ D. cylinder, against the rule.

Where the corneal astigmatism is of small amount at oblique axis, *i.e.*, nearer 45 or 135 than horizontal or vertical, the accepted cylinder will usually be found against the rule, slightly more or less in amount than if the cornea were spherical, with the against-the-rule axis influenced possibly

10 or 15 degrees from 0 or 90, toward the oblique axis found by the ophthalmometer.

To re-state the proposition in another way: It is as if the eyes cited were already fitted internally with, in the case of Patient A, plus 1 D. cylinder, axis 90; Patient B, plus 0.75 D. cylinder, axis 90; Patient C, plus 0.50 D. cylinder, axis 90. You will notice this decrease in the amount of internal or lenticular astigmatism as the age advances; this I will endeavor to account for presently. This must be kept in mind with reference to all eyes, let the corneal astigmatism be what it may. This is why, in our first illustration, Patient A, age 17, having a corneal astigmatism of 1 D. with the rule, requires no correcting cylinder, being already provided with it internally; in the second illustration the same patient having no corneal astigmatism, requires minus 1 D. cylinder against the rule, or, axis 90, to neutralize the internal plus 1 D. cylinder, axis 90. The other illustrations may be decided in the same manner.

In the past, users of ophthalmometers have received the rather vague advice, when they received any at all, to deduct ½ D. from its readings. I offer my rule above as one that I have found dependable under any and all check tests, and applicable to a very high percentage, probably 90 per cent, of cases.

Two questions come to mind at this point that must be noticed: What causes this internal astigmatism, and why does its amount decrease with advancing age?

Without going into details of ocular anatomy further, I believe this astigmatism to be lenticular, and to be caused by lateral pressure on the globe, which affects the lens likewise, of the tendons or attachments of the internal and external recti. The tendons of these, the strongest of the six external muscles, are also the broadest, and are attached nearer to the cornea, than the other four; therefore, their traction being exerted rearwardly, their pressure laterally on the globe would predominate over any tendency displayed by the

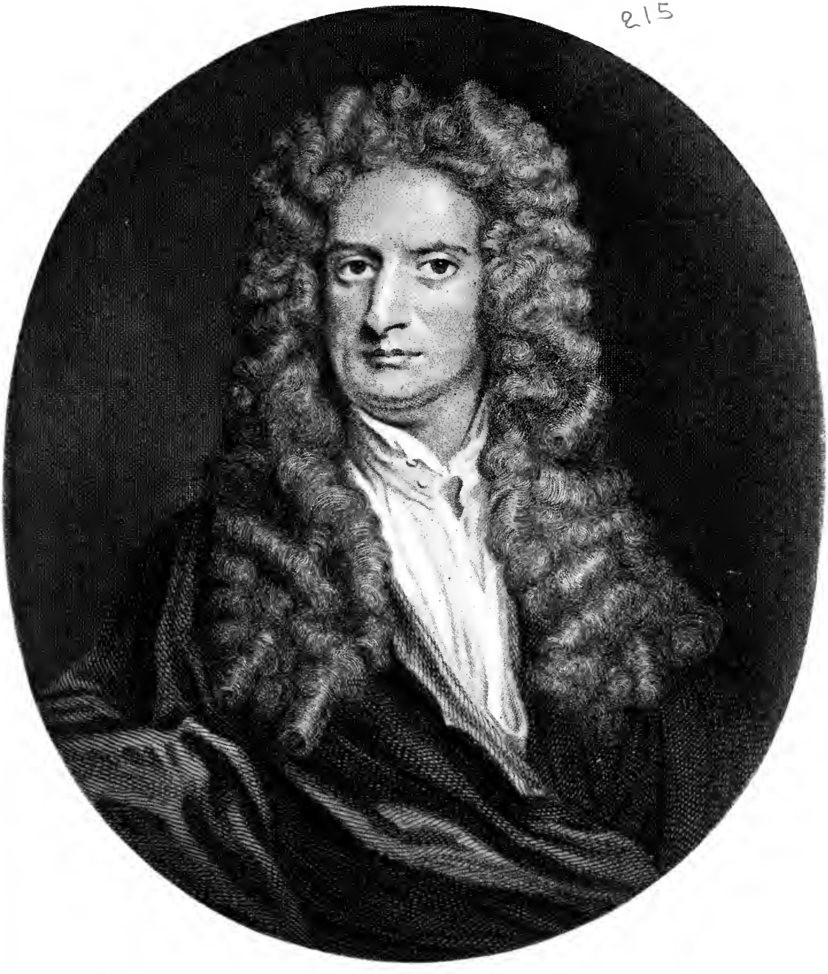
others, and the result would be to give the anterior surface of the lens a toroidal curvature, or, a combination of spherical and cylindrical action. Whether this be demonstrable or not, I consider it both possible and plausible.

The decrease of the lenticular astigmatism with the advance in age, I consider due to the same cause as presbyopia, *viz.*, the hardening of the lens, which reduces the effect of the lateral pressure of the internal and external recti muscles.

When we examine the two causes usually assigned for the decrease in power of accommodation, hardening of the lens, or lessening of strength of the ciliary muscle, only one seems to stand close scrutiny, the first named. Taking the figures usually given as at least a good average, at age 10, the accommodation is given at 14 D.; at age 20, 10 D. Why should the ciliary muscle lose almost half its strength during this period when every other muscle in the body is increasing in strength and endurance? The regular loss of accommodative power is more rationally accounted for by assuming that the lens loses in elasticity, and the same assumption answers the question as to the decrease in the effect of the lateral compression of the horizontal recti muscles, or, the decreased lenticular astigmatism as age advances.

To summarize: The ophthalmometer readings are modified by other conditions which prevent, in most cases, their use literally. The modifying conditions are, in a slight degree, the distance of the lens from the eye, but principally lenticular astigmatism; the lenticular astigmatism is probably due to lateral compression of the globe by the attachments of the horizontal recti muscles, and decreases with advancing age, due to loss of elasticity of the lens.

(Abstracted *verbatim et litteratim* from *Optical Journal and Review* Vol. XLVII, page 63, 1921.)



Isaac Newton.

Sir Isaac Newton

One of the greatest natural philosophers of all time, author of the "*Principia*," discoverer of the "law of gravitation," of the composite character of white light, of the dispersion of light, of the unequal refrangibility of different colors, as well as being the propounder of the corpuscular theory of light.

Born at Woolsthorpe, Lincolnshire, England, on December 25, 1642 (old style) or January 5, 1643 (new style).

Received his Bachelor's degree from Trinity College, Cambridge, in 1662 and his Master's degree two years later.

In 1669 elected Lucasian professor of mathematics at Cambridge.

From 1669 to 1671 he lectured on optics and mathematics and in his optical lectures announced most of his optical discoveries.

In 1672 admitted as a Fellow of the Royal Society.

"*Discourse on Light and Colours*" published in 1675.

In 1704 the first edition of "*Opticks:* or, *A Treatise* of *The Reflections, Refractions, Inflections and Colours of Light*" was published.

In 1685 and 1686 wrote his "*Principia.*"

Died at Kensington, March 20, 1727, aged 84, and was buried in Westminster Abbey.

217

Quotation from Sir Isaac Newton's *Opticks*

"*Qu.* 29. Are not the Rays of Light very small Bodies emitted from shining Substances? For such Bodies will pass through uniform Mediums in right Lines without bending into the Shadow, which is the Nature of the Rays of Light. They will also be capable of several Properties, and be able to conserve their Properties unchanged in passing through several Mediums, which is another Condition of the Rays of Light. Pellucid Substances act upon the Rays of Light at a distance in refracting, reflecting and inflecting them, and the Rays mutually agitate the Parts of those Substances at a distance for heating them; and this Action and Reaction at a distance, very much resembles an attractive Force between Bodies. If Refraction be perform'd by Attraction of the Rays, the Sines of Incidence must be to the Sines of Refraction in a given Proportion, as we shew'd in our Principles of Philosophy: And this Rule is true by Experience. The Rays of Light in going out of Glass into A *Vacuum*, are bent towards the Glass; and if they fall too obliquely on the *Vacuum* they are bent backwards into the Glass, and totally reflected; and this Reflexion cannot be ascribed to the Resistance of an absolute *Vacuum*, but must be caused by the Power of the Glass attracting the Rays at their going out of it into the *Vacuum*, and bringing them back. For if the farther Surface of the Glass be moisten'd with Water or clear Oil, or liquid and clear Honey; the Rays which would otherwise be reflected, will go into the Water, Oil, or Honey, and therefore are not reflected before they arrive at the farther Surface of the Glass, and begin to go out of it. If they go out of it into the Water, Oil or Honey, they go on, because the Attraction of the Glass is almost balanc'd and render'd ineffectual by the contrary Attraction of the Liquor. But if they go out of it into a *Vacuum* which has no Attraction to balance that of the Glass, the Attraction of the Glass either bends and refracts them, or brings them back and reflects them. And this is still more evident by laying together two Prisms of Glass, or two Object-glasses of very long Telescopes, the one plane the other a little convex, and so compressing them that they do not fully touch, nor are too far asunder. For the Light which falls upon the farther Surface of the first Glass where the Interval between the Glasses is not above the ten hundred thousandth part of an Inch, will go through that Surface, and through the Air or *Vacuum* between the Glasses, and enter into the second Glass, as was explain'd in the first, fourth and eighth Observations of the first Part of the second Book. But if the second Glass be taken away, the Light which goes out of the second Surface of the first Glass into the Air or *Vacuum*, will not go on forwards, but turns back into the first Glass, and is reflected; and therefore it is drawn back by the Power of the first Glass, there being nothing else to turn it back. Nothing is more requisite for producing all the variety of Colours and degrees of Refrangibility, than that the Rays of Light be Bodies of different Sizes, the least of which may make violet the weakest and darkest of the Colours, and be more easily diverted by refracting Surfaces from the right Course; and the rest as they are bigger and bigger, may make the stronger and more lucid Colours, blue, green, yellow and red, and be more and more difficultly diverted. Nothing more is requisite for putting the Rays of Light into Fits of easy Reflexion and easy Transmission, than that they be small Bodies which by their attractive Powers, or some other Force, stir up Vibrations in what they act upon, which Vibrations being swifter than the Rays, overtake them successively, and agitate them so as by turns to increase and decrease their Velocities, and thereby put them into those Fits."

218

2\19

The American Journal of Physiological Optics

Life and Optical Researches of Sir Isaac Newton

Ralph E. Sweeting

Nature and Nature's laws lay hid in night
God said "Let Newton be," and all was Light.
—*Pope*

IN the dim ages of the past, when man first took cognizance of the world about him, it is easy to believe that the first phenomena to attract his attention was the constant rotation of darkness and daylight. Whence came this shining orb flooding his habitation with *something* that made his existence easier, and whence did it go, leaving the place a blank?

Anthropologists tell us that even early man was a scientific man, *i. e.* he acquired knowledge from his various experiences and from this knowledge made deductions that guided him in his future actions. But the forces of nature were far beyond his mental grasp. And so it was one of the characteristics of early man that he worshipped whatever he could not understand.

It has always been a source of wonderment to the writer that it remained for the seventeenth century and the genius of a Newton to discover such a simple thing as the refrangibility of light. Simple! Yes, all great discoveries are simple when analyzed by the master mind. The history

The quotation from Pope is taken from the tablet which was placed in the room at Woolsthorpe where Newton was born.

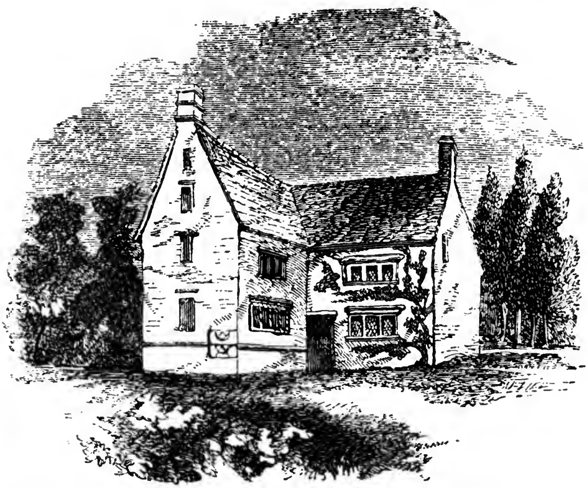
The full page engraving is taken from the celebrated painting of Newton by Sir Godfrey Kneller. The other illustrations are from a lecture by R. E. Sweeting on *Great Men of Optical Science*, and are reproduced here by special permission of Newton & Co., London, Eng.

of glass dates back to early Egypt. The art of glass-making was known to the Phoenicians and the Romans, and many beautiful examples of their work have come down to us. Was there never a time in all these centuries when a ray of light, falling upon some object of glass, was dispersed into its various colors? Probably thousands of times, but no one ever thought of analyzing the phenomena. Science made little progress during these early ages due largely to the attitude of the race toward the forces of nature as evidenced by the elaborate forms of sun-worship found in Egypt and Assyria, and the persecutions of the Middle Ages. The awakening came in the sixteenth century when Galileo defied authority and began to prove his assertions by actual experiment. As a result he died a prisoner of the Inquisition. But his teachings lived. Men began to experiment and to think for themselves. Snell discovered the law of refraction in 1621. In England, Sir Francis Bacon began to preach the doctrine of inductive science. Hooke, Boyle, Huyghens and others came upon the scene and the stage was set for the greatest scientist the world has ever known. Considering the variety and comprehensiveness of his achievements, it has been said that the work of Newton was the greatest that the human mind has ever accomplished.

Isaac Newton was born in the Manor house of Woolsthorpe, in the parish of Colsterworth in the county of Lincoln, about six miles south of Grantham, England, between one and two o'clock in the morning of the twenty-fifth of December 1642, the same year that Galileo died. Newton's birth was premature, and he was a posthumous child, his father having died a short time before. His mother, in after years, told Newton that he was so small at birth that he could have been put in a quart mug. Apparently he was so feeble that two women, who went for some medicine for him, did not expect to find him alive when they returned.

Under the guardianship of his uncle and the tender care of his mother, he gradually began to acquire the strength

Woolsthorpe House, Lincolnshire, the birthplace of Sir Isaac Newton



Manor House, Woolsthorpe, showing the solar disk which he made when a boy.

of constitution required to develop his intellectual powers. At the age of four, his mother married again, and her mother, Mrs. James Ayscough, took up her residence at Woolsthorpe for the purpose of caring for her nephew.

Newton's early education was acquired in two small hamlets near Woolsthorpe. At the age of twelve he was

Newton at the age of twelve

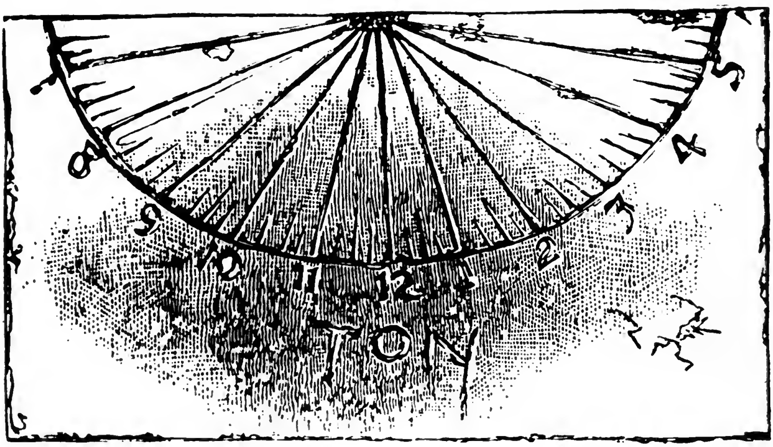
sent to the public school at Grantham. According to the confessions of Newton himself, he was extremely inattentive at his studies and always stood very low in his classes. One day an incident occurred that was to be a turning point in the career of young Newton. When he was last in the lowermost form but one, a boy next above him, as they were going to school, kicked him in the stomach. Quite naturally this occasioned much physical pain and

mental anger. After school was dismissed, young Newton invited this boy out to the churchyard next to the school. Here they were aided and abetted by the schoolmaster's son, who, "clapping one on the back and winking at the other," encouraged both to fight it out. Although Newton was not as robust as his antagonist, he had more spirit and resolution and he succeeded in beating his opponent until he could not fight any more. At the suggestion of the schoolmaster's son, he completed the ceremony by rubbing the bully's nose against the wall.

Grammar School, Grantham

Although he had beaten his antagonist in the church-yard, Newton still was below him in the schoolroom. It was then that Newton resolved to make it a moral as well as a physical victory. He accordingly applied himself to his studies and not only gained an individual victory, but rose to the highest place in the school.

It is possible that there was some excuse for Newton's idleness. He was greatly interested in mechanical contrivances and was continually "knocking and hammering in the room where he lodged." He constructed a water-clock, a windmill, and a carriage that moved by the person who sat in it. This water-clock was quite a useful article



Sir Isaac Newton's Sun-dial in the Royal Society.

and remained in Newton's room long after he went to Cambridge. It is possible that the imperfect measurement of time, which he observed from the water-clock, led to the study of the celestial phenomena. He was frequently seen watching the motion of the sun from the yard of the house where he lived. "He drove wooden pegs into the walls

and roofs of the buildings as gnomons to mark by their shadows the hours and half hours of the day. It does not appear that he knew how to adjust these lines to the latitude of Grantham, but he is said to have succeeded after some years of observation in making them so exact that anybody could tell what o'clock it was by Isaac's Dial, as it was called. It was probably at the same time that he carved two dials on the walls of his own house at Woolsthorpe." One of these dials on the house was taken down and presented to the museum of the Royal Society. The name of Newton, with the exception of the first two letters, may be seen under the dial in rude, capital letters. But saws and hammer were not the only tools with which the young philosopher was employed. He could draw quite well and it is said that he wrote poetry, although nothing has been preserved.

When Newton was fifteen years old, his mother, who was again a widow, moved back to Woolsthorpe, and Newton was taken out of the school at Grantham to learn the duties of farming. One of these was to go to Grantham on market days and distribute the produce. On these occasions he was accompanied by a faithful man servant. Usually the servant was sent to attend to the commercial duties and Newton spent the time among the old books in the garret of the house where he formerly lived. Sometimes he would stay by the roadside delving into some favorite author while the servant would make the trip to Grantham alone. One day, however, his uncle found him under the hedge by the roadside. His mother had already become convinced that he was not a success at farming, so he was sent back to Grantham for a period of nine months, after which he entered Cambridge in 1661.

At college Newton was not a remarkable scholar. In fact, it was said that Newton knew less than the ordinary student on entering. He did, nevertheless, become interested in mathematics, mastering several works without the

aid of a tutor. Among these were Kepler's Optics, Euclid, and Descartes' Geometry. He became quite a prodigy in mathematics: one of the tutors acknowledged before the class that Newton knew a certain text-book better than he did.

It was in the fall of 1665, when the college was dismissed on account of the plague, that Newton made his first observation on gravitation. As for his optical researches we cannot tell exactly when they did begin. In a notebook written in 1664 and 1665 we find observations on refraction, on the grinding of "spheric optic glasses," on the errors of lenses, and so forth.

In 1666 Newton himself tells us that he purchased a prism to try the phenomena of colors.[1] There is no evidence that he used it for this purpose, for in 1669 Dr. Barrow completed and published his optical lectures. Barrow acknowledges his indebtedness to his colleague, Mr. Isaac Newton, for having revised the manuscript to these lectures. In the twelfth lecture there are so many errors upon the philosophy of color that we are sure Newton could not have allowed his friend to publish them had he then known the true theory.

Newton's contributions to optical science consist in his discovery of the refrangibility of the different rays of light and his theory of colors.

In regard to the first, we find that the telescope plays an important part. It had long been known that the lenses then in use did not produce perfect images. This was supposed to be due to the imperfect methods of grinding and polishing. The early pages of the *Philosophical Transactions* are filled with schemes for grinding and polishing these lenses, especially the hyperbolic form suggested by Descartes.

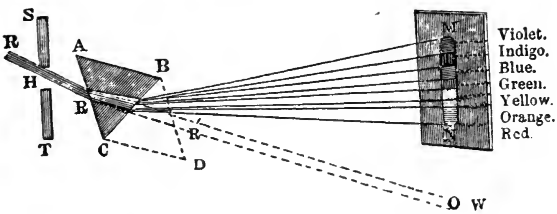
Newton became interested in these studies, and after several attempts at lens grinding became convinced that

(1) Philosophical Transactions, Vol. VI, p. 3075.

the imperfect image came from some other cause than the imperfect convergence of the incident rays to a single point. This happy conjecture was confirmed when Newton made his discovery of the different refrangibilities of the rays of light, — a discovery to which no other person ever laid claim, which is also a very rare thing in the history of science.

The description of Newton's experiment with the prism is interesting: how he made a hole in the window shutter, and then, darkening the room, produced the solar spectrum upon the wall. "It was at first," says Newton, "a pleasing divertisment to view the vivid and intense colors produced thereby." But this pleasure was immediately succeeded by a startling phenomenon, "the extravagant disproportion between the length and the breadth of the spectrum." This excited his curiosity. He transmitted the light through holes in the shutter of different sizes; through different thicknesses of the glass; by putting the prism on the outside of the shutter. He thought that possibly the difference between the length and breadth might be due to some unevenness in the glass itself, so he placed another prism contrawise to the first one, only to find that the image now produced by the combined prisms was a spot of light as regular as the hole in the shutter! Newton next made a critical examination of the angles at which the incident rays fell upon the face of the prism; the length of the spectrum from the prism; the refractive index of the prism, etc., calculating that the rays of the sun should subtend an angle of about 31′ or two and three-eighths inches at the distance at which the spectrum was formed. This corresponded to the *width* of his spectrum, but the length was more than five such diameters, or 2° 49′. Newton could not convince himself that he should doubt the law of sines upon which his calculations were founded, so he concluded that "there still remained some other cause to be found out" why the length of his spectrum should be greater than the width.

Then came the *experimentum crucis*. He placed a board with a hole in it against the face of the prism B C, so that he could transmit through the hole any one of the colors



Newton experimenting with the prism.

in M N. He next placed another board with a hole at N and behind this another prism. Then by rotating the prism

A B C he could successively cause the rays of a single color to fall upon the wall back of the second prism, and he marked upon the wall the place where each color fell. From the variation of these places he found that the red rays were less refracted than the orange or yellow, while violet was refracted most of all. Hence he arrived at the grand conclusion that *light was not homogeneous*, but consisted of rays of different refrangibility. Thus was performed the first experiment in spectrum analysis.

Newton immediately perceived that this was the cause of the imperfections in telescopes. So he left off his "glass works," as he called his attempts at lens grinding, and

Newton's reflecting telescope

proceeded to construct a reflecting telescope. The success of his experiment led him to construct another, of which

we show a picture, and which is still preserved in the museum of the Royal Society.

Meantime, we find Newton a very busy man. In 1669 Dr. Barrow resigned the Lucasian professorship of mathematics in favor of Newton. Then, too, he was conducting his experiments on gravitation, besides working out a method of fluxions.

During the years 1669-70-71 Newton gave a series of lectures on optics at Cambridge, and it seems strange that his discoveries did not become better known through his pupils. But it was upon the reflecting telescope that his fame rested. On December 23, 1671, the Bishop of Salisbury proposed Newton as a member of the Royal Society, and he was elected to membership on January 11, 1672. On this day, also, the Society proposed to transmit a drawing and account of the reflecting telescope to Huyghens at Paris to protect it from foreign piracy.

Newton was justly surprised and pleased at his election and the interest of the Society in his telescope, an invention on which he had placed little value. So he proposed to communicate to them "an account of a philosophical discovery" which led to the invention of the said telescope, and which he considered the "oddest, if not the most considerable, detection which hath hitherto been made in the operation of nature."

Great interest existed among the members of the Royal Society, when, on February 8, 1672 a paper was read before that Society on the "Different Refrangibility of the Rays of Light." The solemn thanks of the Society was voted the author and the paper printed. Our illustration is the introduction to this paper — the first notice given to the world of this discovery — taken from an abridged edition of the early numbers of the *Philosophical Transactions*. You will observe that the editor has appended a note saying that Newton was about twenty-three years of age when this discovery was made.

Newton recognized the advantage of being able to communicate his discoveries to such an impartial and learned body as the Royal Society. So this paper was followed by others dealing chiefly with his discoveries regarding colors.

Newton now applied his discovery to an explanation of several interesting phenomena. It was at last easy to understand why the spectrum was longer than its breadth; why

(ἐκκαιδεκήρης.)

A Letter of Mr. Isaac Newton,* *Professor of Mathematics in the University of Cambridge; containing his New Theory of Light and Colours: sent by the Author to the Editor from Cambridge, Feb. 6, 1671-2; to be communicated to the Royal Society.* N° 80, *p.* 3075.

Sir,—To perform my late promise to you, I shall without further ceremony

* This letter appears as the first public communication of the illustrious author, concerning one part of his brilliant discoveries, viz. the different colour and refrangibility of the rays of light; a discovery truly novel and philosophical, and is the more extraordinary as made when the author was only 23 years of age; as appears by comparing the date of the experiments with that of his birth, Dec. 25, 1642. We shall here only notice farther that he died March 20, 1727, in the 85th year of his age; reserving the more ample account of his life and writings to the intended miscellaneous volume before mentioned.

objects looked at through a prism appeared colored; why, in Hooke's experiment with two wedge-like vessels, the one filled with red and the other with a blue liquid, the two became opaque when placed together. After many other experiments he concluded "That the color of all natural bodies have no other origin than this; that they are variously qualified to reflect one sort of light in greater plenty than another."

Few discoveries have ever caused as much controversy as did these of Newton's. They were assailed by men eminent in scientific achievement with a degree of virulence and ignorance that was astonishing. Pardies, for instance, contended that the elongation of the sun's rays were due to the unequal incidence on the first face of the prism. Also, that the mixture of all the colors did not produce white, but gray. Linus, a physician of Liége,

asserted that he had often observed the difference in the length and breadth of the spectrum, but that this never happened on a clear day with the sky free from clouds! Lucas, who succeeded Linus, confirmed some of the leading results of Newton's experiment, but he could only get a spectrum three and one half times longer than its breadth, whereas Newton stated it to be five times the diameter.

And so the discussions continued as the early papers in the *Philosophical Transactions* can testify. Pardies was not a careful investigator; Linus probably never saw the true spectrum, but only a reflection from one of its surfaces, and Lucas was either insensible to blue or violet or else his prism was of a different dispersive power than the one Newton used. Newton did repeat many of his experiments and with great precision, and it is possible that if Lucas had been more insistent with his objections, Newton would have discovered the different dispersive powers of various kinds of glass, — a discovery of the following century, which led to the invention of the achromatic telescope.

Then followed the celebrated discussions with Hooke, who has been credited with the first suggestion of the undulatory theory of light, and with Huyghens who objected to the doctrine of the union of all the colors to produce white light and of the different refrangibilities of the rays.

As may well be imagined, Newton became disgusted with so much controversy. He had patiently, time and time again, answered these criticisms, and it is said that he spent more time correcting the blunders of others than he did in his own researches. In 1675 we find him writing to Leibnitz:—"I was so persecuted with discussions arising out of my theory of light that I blamed my own imprudence for parting with so substantial a blessing as my quiet to run after a shadow." Again, disappointed because he did not receive a law fellowship,—for there is reason to believe that he contemplated taking up the study of law, — he tried to resign from the Royal Society, much to their surprise.

It seems that, at this time, Newton was in embarrassing financial straits, for the Royal Society offered to suspend his weekly payments. The probable reason was that his fellowship at Cambridge was about to expire. Through a grant from the Crown, however, this was continued, and this, with the income from the Lucasian chair, doubtless enabled him to resume his payments to the Royal Society.

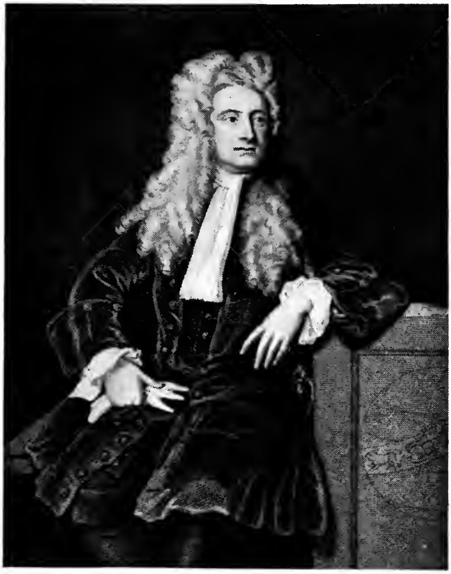
And now, what about the Newtonian, or corpuscular, or emission theory of light as it is variously called?

In December, 1675 the first part of the hypothesis was read before the Royal Society. This was partly an answer to some of his controversies, and also a setting forth of a theoretical statement of his researches for those, as he says, "who must always have an hypothesis to work from." At some length he treated of the ether, refrangibility, color, the colors of thin plates and other like topics. In this paper he distinctly stated that light is a "multitude of small and swift corpuscles springing from shining bodies, red having the big corpuscles and violet the smallest." This paper was read in sections at succeeding meetings and together with other papers of Newton form his Optics which was published in 1704. The only other optical work of Newton was his *Lectiones Opticae*. This was published after his death and consisted of his Cambridge lectures of 1669-70-71.

We may wonder at the persistency with which Newton held to his theory. He was undoubtedly greatly influenced by his previous knowledge. Before he began his optical studies he was intimately acquainted with the laws of elastic collision which can be illustrated on a billiard table. This was a much discussed theory in Newton's day. He knew that, with regard to the collision of sensible masses, the angle of incidence and reflection were equal. His study of gravitation had deeply imbued his mind with these notions and it seems that he followed the same line of thought when he took up the study of light, seeing in refraction

similar attractive forces exerted on the light particles.

These comments upon the Newtonian theory are based upon statements by Newton's biographer, Brewster. The writer is much impressed with the remarks of Gibson who



goes to a great deal of trouble to say that we are not paying any compliment to Newton when we speak of the "Newtonian Theory," for Newton would have been the first to change his ideas had there been any reason for doing so. Newton points out repeatedly that, for himself, he would rather not adopt any theory as to the nature of light, and he emphasizes the fact that he is only bringing forward this picturesque view of the matter for the benefit of those who cannot understand the phenomena of light without some such idea. We must remember too, that, although suggestions had been made especially by Hooke that light was of the nature of waves, there had not been offered a particle of experimental evidence.

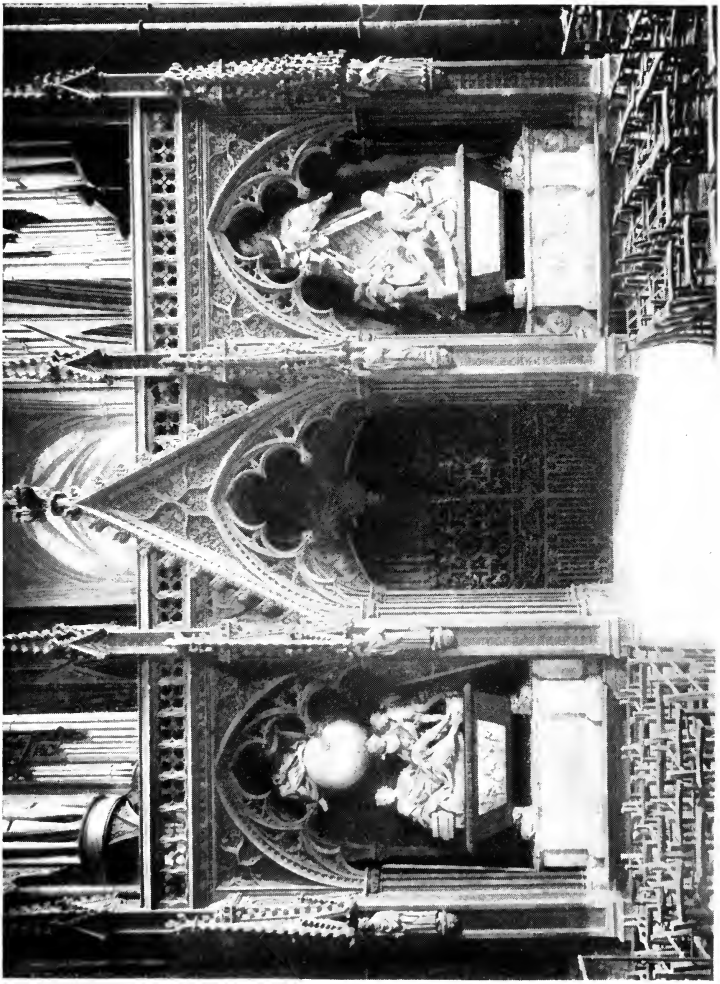
Fascinating indeed is the study of these early discoveries in optical science — of the men who made them and of how it was done. We have barely outlined the work of Newton, which we must observe was accomplished while he was a young man. With his discovery of the law of universal gravitation, his mathematical and astronomical discoveries we are not concerned at this time. He was at one time Master of the Mint, was twice elected to Parliament, and in 1703 was elected president of the Royal Society, a post which he held for a period of twenty-four years and up to the time of his death. It has been said that, if Newton had accomplished nothing else, the theological studies of the latter part of his life would have given him a high reputation.

In personal appearance, Newton was not above the medium height. It is said that he had "a very lively and piercing eye, a comely and gracious aspect, with a fine head of hair as white as silver."

In all sketches of his life his character receives much comment. He became rich through his prudence and economy, but was always generous. He was the most modest of men, thinking little of his world-startling discoveries, and he himself said that all that he accomplished was due to hard and persistent labor.

He never married, but lived with his niece and her husband. During his school days at Grantham, there were several young ladies in the house where Newton boarded. One of these, a Miss Storey, who after her second marriage was then a Mrs. Vincent, confessed at the age of eighty-two years that young Newton had been in love with her. But the smallness of both their incomes prevented their marriage. Newton's esteem of her continued unabated throughout his life.

On the second day of March, 1727, in his eighty-fifth year, Newton journeyed from Kensington to London to preside at a meeting of the Royal Society. The following



The Newton Memorial in Westminster Abbey. (At the left side of the picture).

day he suffered a violent attack of a complaint which had troubled him the last few years of his life. He died on the twentieth day of March, 1727, his faculties and senses vigorous until the last day of his life.

Newton was buried in Westminster Abbey. The memorial erected by persons who inherited his personal estate was assigned by the Dean of Westminster to one of the most conspicuous positions in the Abbey — a place which had often been refused to nobility.

No words of ours can as fittingly eulogize such a career as do those inscribed upon the Abbey monument:

Here lies
Sir Isaac Newton, Knight,
Who, by a vigor of mind almost supernatural,
First demonstrated
The motions and figures of the Planets,
The paths of the Comets, and the Tides of the Ocean.
He diligently investigated
The different refrangibilities of the Rays of Light,
And the properties of the Colours to which they gave rise.
An Assiduous, Sagacious, and Faithful Interpreter
of Nature, Antiquity, and the Holy Scriptures,
He asserted in his Philosophy the Majesty of God,
And exhibited in his Conduct the simplicity of the Gospel.
Let Mortals rejoice
That there has existed such and so great
AN ORNAMENT TO THE HUMAN RACE.

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A Physiological Explanation of Certain Optical Illusions[1]

P. F. Swindle, Ph. D.

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A. Introduction and General Discussion

A DISCUSSION of optical illusions necessitates the use of a number of terms which, at the present time, have so many meanings that it seems advisable to give the reader a definite idea of their significances in this article. The following paragraphs of the introduction contain discussions of some of the more important of these terms.

If the retina is stimulated by a white sheet of paper, a pattern of visual responses is produced. The sheet of paper is a pattern of stimuli; and the many responses which it calls forth may be spoken of collectively as a visual pattern response. If the paper is removed under such conditions that the retinal region in question is acted upon by another color, this second color sets up another pattern of visual responses which ordinarily greatly diminishes the effect caused by the white paper. The weak, positive after-effect of the white paper which remains after the inhibition is a memory image. The pattern response before inhibition is appropriately called a percept; but it is essentially a positive after-effect, as can be proved in the following way: Illuminate the paper for a very brief interval and then turn out the light, leaving the retina in total darkness. If the observer takes special care to hold the eyes and other bodily members entirely still, the probability is very great that he will continue to see the paper almost as distinctly

(1) In order to gain at once a fairly accurate idea of the contents of this article, the reader may examine the statements made in direct reference to any one of the figures 1 to 8 inclusive, but preferably Fig. 1. While doing this he should hold the observation in mind that the self-inductive capacity of a color varies with the stimulus area.

as he did when the light was burning. This observation means only that the visual pattern of responses was merely started by the paper and that the effect is not dependent—after an almost inappreciably short period of stimulation —upon the presence of the paper for its continued existence. In the dark room we find the positive after-image continuing because there are no visual stimuli in the darkness to inhibit it. In ordinary daylight we find the positive after-image continuing as long as the eye is directed to the paper that initiated the pattern response. This paper does not inhibit the effect which it called forth; so, as long as the eye is directed toward the white paper, the observer is seeing a positive after-image of the paper under the most favorable conditions attainable.

As a background for the positive after-effect, the paper is superior to darkness because the paper not only prohibits (as darkness also does) other visual stimuli from acting directly upon that portion of the retina, but it calls forth repeatedly the visual responses for which it is an adequate stimulus. The positive after-effect in ordinary daylight (the diurnal positive after-effect) is accordingly more distinct than that observed in darkness (the nocturnal positive after-effect), since the white paper in daylight not only protects the effect it starts but causes the various visual elements to function repeatedly after very short recuperation pauses.

Both varieties of the positive after-effect grow weaker in time. The nocturnal effect eventually becomes gray and then darker than the surrounding darkness of the room. The diurnal effect passes only more slowly through corresponding stages. The later portions of each of the after-effects we may call negative after-effects, indicating that a marked qualitative change has occurred in the appearance of each of the original after-effects.

The expression "self-induction of colors" is important. It is a name for a type of observations which are easily made and to which reference will frequently be made in the

body of this paper. After a momentary illumination of a white paper in the dark room, a whitish border or halo effect appears around the positive after-effect of the paper. This becomes broader and broader until it covers a considerable portion of the field of vision. *This border effect owes its existence to the positive after-effect which induces itself over neighboring regions of the retina.* The self-induced effect appears later and may therefore be quite distinct after the positive after-effect proper has become negative. In daylight the same general phenomenon can be determined. If one fixates a point on the white paper very carefully, indirect observation of the background shows that it becomes gradually whitish. We may say then that the white of the paper induces itself over the background. It can also be observed that the background color induces itself over the white of the paper. This self-induction can be verified by using different colors for the background. If the background is blue, it will eventually become whitish as the white of the paper becomes bluish. Likewise, if the background is red, it will become whitish as the paper becomes reddish, and so on with other colors that we may choose.

A further observation of great importance in the study of optical illusions is that *the self-inductive capacity of a color varies directly with the stimulus area.* This is equivalent to saying that the more expansive the retinal area stimulated the stronger is the response — a greater number of visual structures function at the same time — and that a strong response will affect neighboring retinal regions in a positive way sooner than a weaker one will. Let us first see how this law of color induction can be verified by working in the dark room. Illuminate momentarily two patches of white, a large and a small one. The larger of the two areas will not only last longer but a much more expansive white halo will develop around it than around the smaller area. To verify the law by working in daylight, fixate a

large white paper on a blue background and at another time a small white paper on the same background. In the first case white can be observed on the blue much sooner than in the second case, and in the second case the blue appears much sooner over the small area of white.

The term color will mean any visual effect that can be made to induce itself in a demonstration. Even blacks and whites will then be called colors. Darkness should not be confused with our illuminated blacks. It does not seem to induce itself and is therefore not a color.

Physiologically, a line is a blur which is cut down to a mere core by the background colors; we ordinarily perceive only the core. This conception is also of much importance in the study of optical illusions, but before applying it the principal reasons for its formulation should be presented. The remaining paragraphs of the introduction will serve this purpose.

Everyone who has photographed the movements of the eyes, made examinations with the ophthalmoscope or retinoscope, or has attempted to observe the fibrous elements of the vitreous mass of his own eye by looking into a microscope focussed in certain ways, is aware that the eye is never still. The eyeballs seem to move constantly in every possible direction. Also, anyone who has measured the intra-ocular pressure, is aware that it may change in a rapid tempo. The movements of the crystalline lens and the changes in the shape of the eye at each pulse beat complicate the situation still further. Theoretically, a distinct image of a physical line is possible only under the condition that the lens is accommodated for the line and that the visual apparatus remains entirely quiet. A blurred image of the line is the natural consequence of the movements of the eye. We would perceive a blur, instead of the mere core of it, if it were not for the circumstance that the weakest portions of the blur are always cut down by or neutralized by the blur of some background color. A blue line on a

blue background of the same quality is certainly not very distinct, since it can exist in imagination only. A blue line on a yellow background, however, is perceptible. The blur of the blue is eliminated by the qualitatively dissimilar blurs of the yellow on either side of the blue. The more antagonistic the blurs are the sharper is the line or the smaller is the core. *If the blur is acted upon by unequal forces, a strong one to the left and a weak one to the right, the perceptible core of the blur will lie slightly farther to the right than if the forces were equal or interchanged.* Instead of saying a strong force is to the left and a weak one to the right, we may say instead that a larger area of yellow is to the left than to the right of the blue line. The larger area to the left will also induce itself more strongly to the right and over the blur of the blue than the smaller area to the right will induce itself to the left and over the blur of the blue.

In order to study further the cutting down of a blur to a mere core, we can examine a small source of light in a dark room. If the room is so dark that no objects can be distinguished in the background we observe that the spot of light is generally, if not always, a blur. It is also more blurred at times than at others. It either appears to change its size or to recede and advance occasionally as it becomes more and then less blurred. At times the spot seems to do both, *i. e.*, move and change its size. Evidently this apparent behavior of the spot results from one or more of the varieties of behavior of the eye.

It is possible that someone might contend that the eye cannot accommodate as well for the spot in the dark room as it can when a larger number of objects are seen at the same time, as in daylight. The opposite contention, however, would seem to be the more plausible one. It seems as if the eye tends to be more active when stimulated in a great many ways at the same time, as in daylight, than when stimulated by the single spot in the dark room. Some

observations which support this statement are the following: (1) Place a microscope on a large, homogeneous background, hold the eye about five centimeters from the ocular of the microscope, and focus the instrument so that shadows of various elements of the vitreous mass seem to be projected into the microscope tube. These shadows move as the eye moves, some with the eye and some against it. The shadows cannot be kept still; if they are not actually moving back and forth in planes perpendicular to the optic axis, they are pulsating in the same tempo and also in a more rapid tempo than the heart beat. This last mentioned movement is probably of the Brownian type. If the homogeneous background of the microscope is now replaced by a heterogeneous one (it matters little how the heterogeneity is produced), the shadows begin at once to make unusually large movements from side to side or along the optic axis. The eye is then directly affected by the more complex background and begins at once to respond more vigorously. (2) When the eye of an anaesthetized cat or dog is shaded, by holding the hands over it, a needle thrust through the cornea into the lens begins at once to make movements of smaller amplitudes than when the eye is exposed to stronger light.

Aside from the blurring of the spot in darkness and in daylight due to the behavior of the eye, the effect is increased by normal irradiation and by normal conditions of astigmatism (not to mention the abnormal conditions of astigmatism which frequently exist). Darkness does not inhibit such effects, but they are diminished in daylight by the blurs and the self-induced effects of the background colors.

B. Application of Previously Developed Principles to Some Common Illusion Figures

In Fig. 1 we have two colors, white and black. The presence of the black wings at the ends of the equal and horizontal black lines cause the latter to appear unequal

in length, the upper one appearing shorter than the lower one.

As measured by the angles *a*, *b*, and *c*, *a* and *c* are whites of equal magnitudes inducing themselves upon the slanting lines. The area *b* can be resolved into two forces, one of

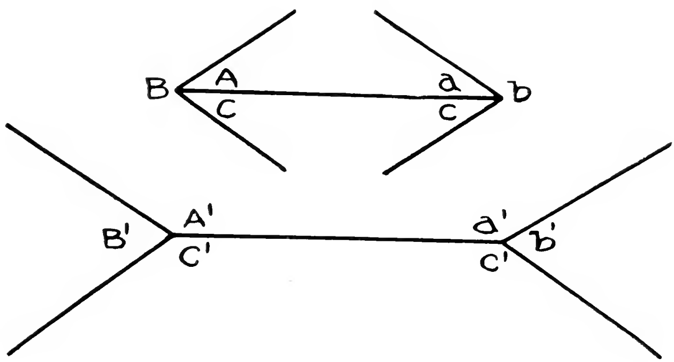

Fig. 1

which induces itself over the upper slanting line and the other over the lower slanting line. In general, we may speak of the forces *a*, *b*, and *c* which act upon the slanting lines and cut them down from more or less indistinct blurs to the mere cores which we speak of as lines. In both cases the greater forces act upon the lines from the outside while the smaller forces act upon them from the inside. This means that the lines are cut down more from the outer than from the inner side. At the left of the upper system of lines the same thing occurs, except that in this case the larger force is to the left of the slanting lines and accordingly they are cut down more on that side. The extent to which they are cut down at either end of the system might not be appreciable, but the forces at the two ends are exactly opposed, thereby doubling the amount of shortening of the

entire upper figure. In the lower system of colors we have similarly unequal forces acting upon the slanting lines, but from such directions that the horizontal is apparently lengthened instead of shortened as in the upper system. Area a' is a relatively large force opposed by the smaller force b', and the large force c' is likewise opposed by the smaller force b'. The forces A', B', and C' at the other end of the lower system produce similar but opposite effects. Therefore, even though the horizontal in the lower system is made shorter than if the opposing forces at the two ends were equalized, it is not shortened to the same extent that the horizontal in the upper system is.

We must remember also, that each area on the figure is a positive after-effect which shifts with each eye movement and that the positive after-effect of a large area is stronger than that of a smaller one and can therefore be carried farther over a different color without being inhibited. The after-effect of the white area which survives longest cuts down a blur more than a weaker effect does in passing over the blur at the same rate. If the eye moves a little to the left, the relatively strong positive after-effect of the large area *b* will be carried farther over the slanting lines than the weaker effects of the smaller areas *a* and *c* will be carried across the same lines when the eye moves to the right. For the sake of greater clearness in thinking let us suppose that we are looking directly at the sun and indirectly at the moon to the right of the sun. Now, we move the eye to the left edge of the moon. The results are: (1) The weak positive after-effect of the moon shifts to the right and is inhibited by other colors; (2) the moon stimulates a new retinal region and sets up a new pattern response there; (3) the strong positive after-effect of the sun shifts to the left edge of the moon and survives long enough to seem to 'eat away' a part of the moon. In this particular instance we obtained inequality in strength of the after-effects by choosing two areas of different absolute intensities; in our illusion

figures different absolute intensities of the stimuli are obtained by drawing the lines in such a way that some of the areas are small and some large.

If eye movements are an important factor in our judgment that the upper horizontal line is shorter than the lower one, we should be able to eliminate the illusion—not entirely but only to an appreciable extent—by fixating very carefully some point among the systems of areas. This result is easily obtained. Similarly, if we look first di-

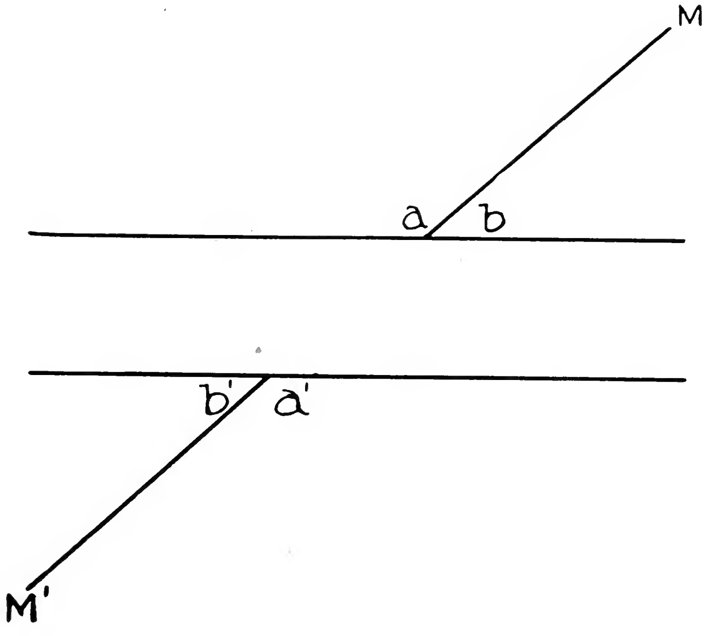

Fig. 2

rectly at the sun and then at the moon the latter will be partially or totally 'eclipsed' by the strong image of the sun, while if we hold the eyes on an imaginary point between the sun and moon we will be able to see both objects clearly for a long time.

The line MM' in Fig. 2 is a straight line with the part between the horizontal lines lacking. After discussing Fig. 1 in detail, it needs only be mentioned here that the area a is greater than the area b, that the area a' is greater than b', and that approximately the same amount of white is to the right as to the left of the points M, and M'. The upper segment of the line therefore appears to revolve in the

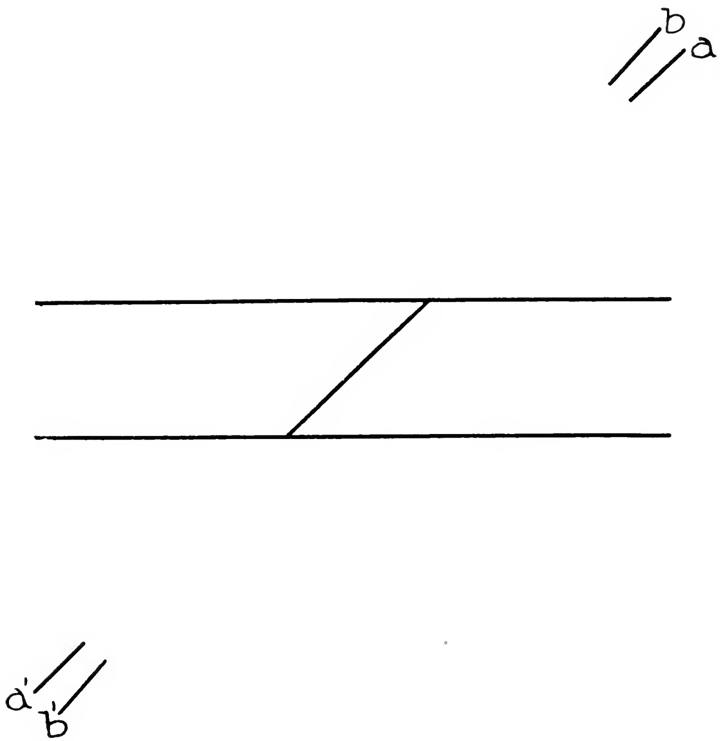

Fig. 3

counter-clockwise direction as if pivoted at M, and the lower segment appears to rotate in the counter-clockwise direction

as if pivoted at M'. The bends that seem to occur in the horizontal lines can be easily explained in terms of the same law of color induction.

In Fig. 3 we have essentially the same illusion as in Fig. 2, but this time it is produced by using the same horizontal lines and only the segment of the transverse line which was absent in Fig. 2. This segment, if projected in both directions, would actually meet a and a'. However, the forces within the horizontal lines act upon the segment from such directions that it is apparently rotated in the counter-clockwise direction as if pivoted at its midpoint. The extent of apparent rotation fluctuates considerably. Frequently, it seems as if it would meet b and b' if extended in both directions.

The horizontal lines of Fig. 4 are parallel, but they

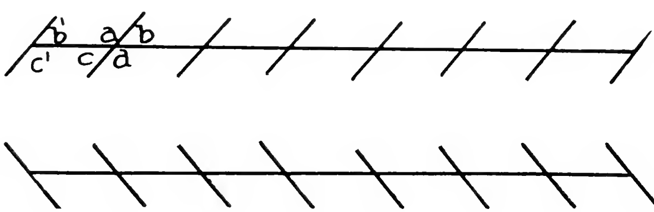

Fig. 4

appear to diverge at the left. Since area a is greater than area b, the segment of the transversal above the horizontal should appear to rotate in the counter-clockwise direction as if pivoted at its upper end, and a should appear to push the horizontal line down more than b does. Since area d is greater than area c, the lower segment of the horizontal should appear to rotate in the counter-clockwise direction as if pivoted at its lower end, and d should appear to shove the horizontal line up more than c does. Moreover, the large area d is opposed by the smaller area b above the horizontal and the large area a is opposed by the smaller

area *c* below. This means that the horizontal l'ne just to the right of the transversal should appear to move up because the blur is cut down more from below, and that it should appear to move down just to the left of the transversal because *a* cuts the blur down more than the smaller force *c* does. The area *c′* cuts the horizontal down more than the area *b′* does. This segment between the two trans-

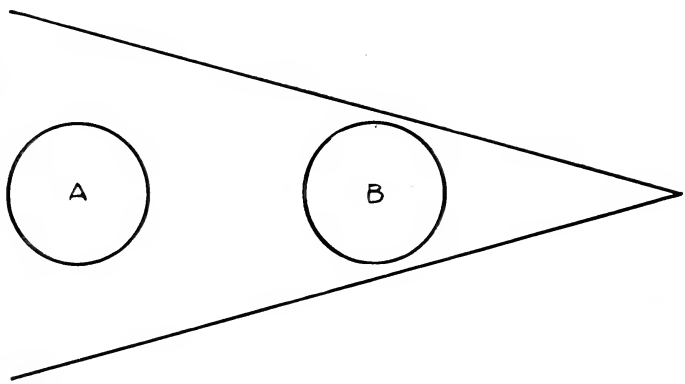

Fig. 5

versals should then appear to rotate in the clockwise direction, and as if pivoted at its midpoint. A similar rotation occurs between each pair of transversals. The rotation of the segments of the lower horizontal line should be in the clockwise direction. The ends to the extreme right are thrown a little closer together than if the transversals were absent, and the ends to the extreme left are thrown a little farther apart than if the transversals were absent. The advantage in drawing transversals at intervals along the horizontal lines instead of a pair of them at either end of the horizontal lines is that we are enabled to appreciate the illusion upon looking at any point of the figure.

Aside from explaining the illusion in question, our

tendency to overestimate acute angles and underestimate obtuse ones in plane figures is also explained.

In Fig. 5 the circle nearer the angle formed by the black lines seems to be larger than the circle farther away from the angle. The same amount of white is within each of the circles, but there is less white outside *B* than *A*. Therefore *A* is cut down more from the outside. *B* not only appears to be larger than *A*, due to the presence of the black lines of the angle, but it also appears to be slightly elliptical to many observers—the long axis of the ellipse being vertical. This is due to the fact that much white is to the right and to the left and little white above and below the circle.

The circles *A*, *B*, and *C* of Fig. 6 are equal, but *C* appears to be larger and *A* smaller than *B*. Because of the black

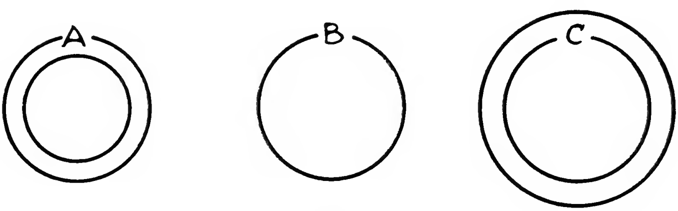

Fig. 6

line around *C*, this circle is cut down primarily from the inside. *C* is therefore larger than if it were cut down from the outside as well, as is the case with circle B. Because of the black within the circle *A*, this one is cut down primarily from the outside. *A* is therefore smaller than if it were cut down from the inside as well, as is the case with *B*. The differences in the apparent sizes of the circles are very small, but they are appreciable to the majority of observers. Essentially the same thing can be said of the other illusion figures here discussed. If the differences were very great, it would certainly not be advisable to attempt to explain them in terms of our law of color induction.

The circle of Fig. 7 seems to be flattened at each of the corners of the square it circumscribes. At every point, *e. g.*, at *a* and *b*, outside the circle there is an equal amount of white, while within the circle the amount of white varies from point to point. Inside the circle at *a* the amount of

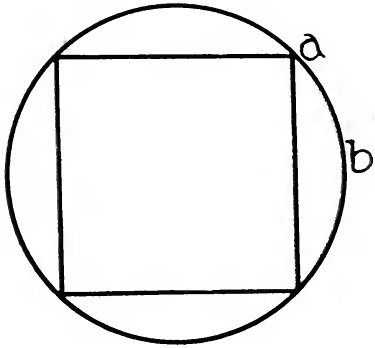

Fig. 7

white is less than at *b*. The circle is therefore cut down more from the inside at *b* than it is from the inside at *a*.

The lines *A* and *B* in Fig. 8 are equal in length, but *B* appears to be the shorter. Relative to the amounts of white at the ends of *B*, small amounts of white are at the

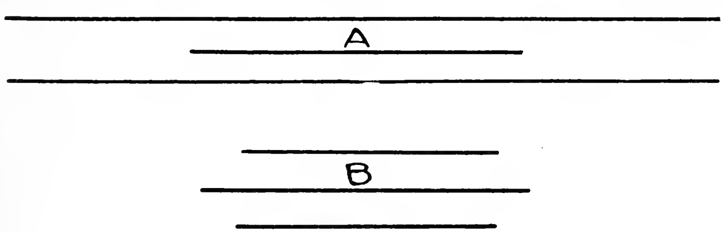

Fig. 8

ends of *A* to cut down the line to make it shorter. *A* accordingly appears to be longer than *B*.

The illusion figures discussed in this paper are only representatives of a large number which could be considered in essentially the same way. In certain instances, however, the complexity of the figures prevents one from seeing at once the application of the principles here used. I have considered the self-induction of colors to be the most important physiological factor responsible for certain illusions which can be appreciated by observing some cleverly arranged systems of colors that permit summations of otherwise inappreciable effects. The self-induction of colors is only the most important physiological factor; there are others of less importance, the greater number of which have been discussed freely in the literature on optical illusions.

It might be useful to some investigators to explain that the idea of applying the law of self-induction of colors to optical illusions originated while the writer was observing positive after-images of various illusion figures. These observations were made in the dark room, so the positive after-images were of the nocturnal type. In the course of an after-image of a given illusion figure, various effects can be observed; the usual illusion may be pronounced for a few seconds, then it may disappear, and then it may be just the reverse of the original one. For instance, in Fig. 4, the horizontal lines may first appear to diverge at the left, then they may appear equidistant at the ends, and later they may appear to diverge at the right. With other figures the sequence of appearances may be quite different. Often, too, so many disturbing factors enter into this type of investigation that it is difficult to obtain consistent results from different observers, as well as from a given observer at different times. If the observer is fatigued he may obtain an unusually distinct positive after-image of the figure, but he may be quite unable to detect any illusion. On the other hand, if he inhales carbon monoxide for a short time he may then be able to obtain a remarkably distinct positive after-image and to observe a series of illusions in

the after-effect. Very deep inhalations for two or three minutes generally causes the same effects. There are, however, individual differences in these respects.

There is one especially disturbing factor which should be noted. Frequently, an important part of the figure vanishes suddenly, while the other parts of it remain distinct. This can be illustrated best by referring to the human hand. Generally, one can obtain a distinct positive after-image of the entire hand and observe that all parts of it disappear at the same time, but sometimes a finger is absent from the beginning. Also, the hand may be complete at first and then lose a finger suddenly. If the finger returns, either a part or all of the rest of the hand disappears. It seems advisable at this time to attribute this phenomenon to a tendency of certain retinal areas to function alternately when stimulated in the same way. This seems to be true to a limited extent of areas of a single retina, but true to a much greater extent of the retinas of the two eyes.

In general the effects in the nocturnal after-image can be predicted when we consider that a small area of white enclosed in black lines will become dark or cloudy before a

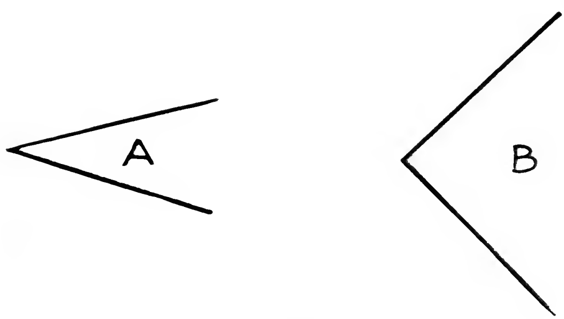

Fig. 9

larger one will. This, however, is equivalent to saying that the self-inductive capacity of a color varies with the stimulus

area. To illustrate, in Fig. 9 we have in *A* a relatively small area of white partially surrounded by a certain amount of black, and in *B* a relatively large area of white less perfectly surrounded by the same amount of black. Both *A* and *B* will eventually become black, but *A* will turn black first, because the black of the lines will induce itself over *A* more readily than the relatively less amount of black per unit area about *B* will induce itself over the relatively large area *B*. *A* becomes black at the apex first, because there is a greater concentration of the black of the lines at this point, and this black seems to act as a nucleus that grows rapidly. It may have the appearance of Fig. 10 before *B* changes appreciably. When the white at the apex has become black the remaining white area is still angular,

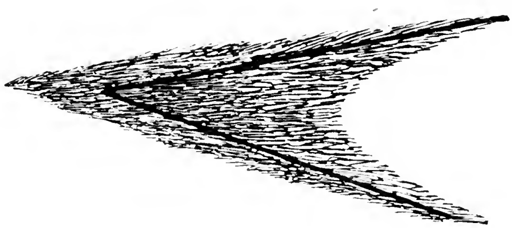

Fig. 10

but more obtuse than usual. When the white paper as a whole becomes dark that part of the figure, which is represented as black in Fig. 10 and which has been black for some time, may change to white. In this case the angle will be abnormally acute, *i. e.*, the illusion will be just the reverse of that in Fig. 10.

There must accordingly be times in the after-image of an illusion figure when the illusion is about equal to that in the diurnal effect, when it is greater than that of the diurnal illusion, when there is no illusion appreciable, and when the illusion is just the reverse of that obtained in day-

light. These effects are observed with considerable consistency by the observers who have had long training in obtaining positive after-images in darkness.

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Editorials

Eye Defects and Eyestrain in Industry.*

INDUSTRY is summed up in one word: production. Whether the form of industry involve the cunning of the hand or the skill of the brain, the ultimate aim and object is to produce that which will be of some service and value to somebody. In the successful carrying on of business by any industrial concern there are two important factors which demand attention: quality and quantity. The first named recommendation for a product, namely, quality, has been during the past few years, by reason of world conditions, somewhat secondary to the second requirement, quantity. With the world as it *is* today—and that is the only way to take it and the only basis upon which to act, rather than to dream too much of what we would like it to be—in business and industry, which means the possibility of every working man and woman having a chance to earn a fair wage, we are certain that both quality and quantity must be considered. In the past too great a consideration has been given to the efficiency of machines of iron and steel and not enough consideration has been given to the matter of the efficiency of human machinery, or the proper functioning of the mechanisms which constitute the finest machine ever conceived of— men.

Quite a little has been done in the past and much more needs to be done in the matter of the correction of the visual defects and eyestrain of school children. As a rule parents will insist upon having every advantage and oppor-

* The major portion of the reports and statements of conditions found in industries are taken from (1) Bulletin I, *Eye Conservation in Industry*, published by the Eye Sight Conservation Council of America (2) Mr. Frederick Hamilton, of Providence, R. I. and (3) from factory sources available at the American Optical Company.

tunity for progress given their children and will sacrifice to that end, but either through carelessness, ignorance, or a feeling that they are old enough "to know if anything is the matter with them" they do not give heed to their own defects. It might be assumed by many—and amongst this number would be employers and heads of big industries—that adults are capable of perceiving their own visual deficiencies and that they would take steps to have their inherent visual defects, or reflexes quite evidently attributable to overworked eyes, corrected or relieved of their own initiative. But experience proves that the majority of adults do not do so. To be sure, it may be supposed with propriety that it is each person's own business whether or not he sees as he should or whether he suffers undue fatigue. On the other hand, it may be just as appropriately stated that this principle of "state rights" is perfectly fair as long as no one else is involved, inconvenienced or the economic loser. But everyone is affected by anyone who works inefficiently. Employers—and that means the general public in the end, for they are the ultimate paymasters—have not realized in the past the economic importance of healthy workers as a general proposition and certainly have had but little appreciation of the relationship between eye defects and eyestrain and production. "The eye as a factor in the consideration of waste in industry is of prime importance, entering directly into the subject of the efficiency of the individual. It is proper that special stress should be laid upon eye defects as contributing greatly to fatigue and waste. Unnecessary fatigue, that waste of human energy and the waste of material resulting through defective vision and the loss of time from eye injuries through lack of protection are potent factors in industrial waste which demand consideration, viewed from the coldblooded standpoint of economics, to say nothing of the humanitarian aspect."

This is a problem the practical solution of which is of

vital importance to everybody. The matter cannot be left wholly to the volition of each industrial worker, for the reason that these individual workers are not cognizant of their condition in the majority of cases. For persons handicapped with imperfect vision are generally not aware of it. Neither is it a matter of the degree of intelligence or education possessed. The writer had the pleasure of being engaged in the examination of the eyes of students in one of our large western universities. Hardly a day went by that he was not led to marvel at the apparent lack of knowledge these students had with reference to themselves. These students would doubtless have gone on for years carrying along their eye defects and ocular derangements had not these examinations been a matter of routine and not of their own volition. Universities and colleges are commonly considered by so-called business men as being about the pink of business inefficiency. Doubtless they are not and cannot be run on schedules such as are employed by factory superintendents, but these institutions of learning are believers in the fact that the business of giving an education can be pursued to much greater advantage if a *whole* boy or girl goes to school and that the greatest avenue of the acquisition of knowledge is through the eye. But the employer and the public have not appreciated these facts, chiefly for the reason that few have attempted to present them and to make plain, everyday matter-of-fact statements with a total elimination of the element of personal gain through an increased clientelle accruing to the person presenting the matter. The writer feels that the world is ready and willing today to have the truth told and that people are desirous of being educated on the care and preservation of the best investment they possess—their bodies.

But, alack and alas! This information and this coercion to bodily care and conservation have not, in general, come from men of authority and professional men of the highest type. The barriers of what is known as "professional

ethics" we feel have been too rigidly built and too meticulously maintained, to the end that the public fail to be instructed in matters of the utmost importance. One's conduct has been judged as being unscientific and unprofessional should he engage in the telling of what he and others believe to be the truth, in a manner which the ordinary person might understand and appreciate. We are not writing a brief in favor of trying to popularize all forms of knowledge. But we are certain of the fact that it was not beneath the dignity of Helmholtz to deliver popular lectures on physical and physiological science, which were subsequently widely quoted in print. We are certain of the fact that the housewife, the farmer, the automobilist and scores of others gain an immense amount of very valuable information from the medium of short paragraphs in newspapers and popular magazines. If it is a good thing to tell the reader how to grow three potatoes where only one before was possible, why should it be considered as debasing if men of skill and ability tell of the things which, from the bodily standpoint, go to make up a life of the best service possible? By reason of this very attitude many of us are inclined to believe that incorrect, poorly selected and often badly tainted information reaches the public. Surely it would be unprofessional and unscientific to claim to cure, remedy or alleviate any physical defects or mal-functionings in any particular case on the part of any kind of a practitioner. But we cannot believe it to be unprofessional if there come from the mouths and pens of our reliable and substantial practitioners statements which portray actual conditions found in various localities and in various industries or trades. It is only in this way that the employer and the employee can be impressed with the economic and humanitarian benefits which accrue, in greater or lesser proportion as the case may chance to be, from rectification of defects. With this in mind we are quoting a series of facts which doubtless represent fairly accurately the

conditions found with reference to eye defects and eyestrain in industry.

In the Whiting-Davis Company, in which a major portion of the employers' eyes were tested, it was found that 8.3 per cent wore satisfactory glasses, 8.4 per cent did not need glasses and 83.3 per cent needed glasses.

It is stated that, after being properly cared for, nearly thirty per cent improved productivity was noted in comparing two months. We do not believe much emphasis can be placed upon any such a statement as the foregoing, for it is extremely difficult to duplicate all factors, get records on production before the correction of visual defects and unbiased data on such production afterwards. It seems to us that many examiners working amongst people of various trades and even parts of these trades will have to compile data for some time yet to come before any answer can be made as to the probable per cent effect on production. We are inclined to believe that quantity will not suffer as much as quality.

Obviously, failure to see sufficiently well to determine details in a manufactured product and to detect flaws will markedly affect the average quality of the product reaching the ultimate consumer. For example, at the Hood Rubber Company it is reported that 20 per cent of the inspectors were found to be unable to see sufficiently well to determine defects. In the inspecting department of the Providence Base Works of the General Electric Company, 40 per cent were found to have sufficient eye trouble to interfere with their work. Of these 23 per cent—hence 10 persons out of every hundred—had vision so low that they were unfit for their positions. The condition of eyesight of the inspectors of products is even more important from the buyers' standpoint than is that of the workman. And it is a question whether or not this same statement is not true from the manufacturers' standpoint also, for quality is a great factor in business success these days.

In the work of the Life Extension Institute, it was found that, in an examination of more than 10,000 employees in factories and commercial houses, about half had uncorrected faulty vision. In the Underwood Typewriter Company 58 per cent were found in need of ocular corrections. At the Frank Mossberg Company Plant, Attleboro, Mass., it was found that about 70 per cent either needed corrections or needed changes. The Rhode Island branch of the New England Telephone Company is examining all new applicants. Thus far about 30 per cent have been found with defective vision which can be sufficiently improved with correcting lenses and about 5 per cent have been disqualified as their sight was too poor to enable them to be efficient.

The J. & P. Coates Company of Pawtucket have adopted the army visual standards. These standards require one to have normal vision in one eye and not less than 2/5 normal in the other. It is found that, after proper ocular attention has been received, not more than one per cent fail to meet their requirements. About this same per cent holds in the case of the General Electric base works at Providence. As a result therefore it is evident that Labor has nothing whatever to fear from any such factory inspections and examinations. On the other hand, it has everything to gain.

The frequency of subnormal vision has been determined in several series of investigations. Dr. Schereschewsky found that, in a total of 2,906 garment workers, only 743 or a little over 25 per cent had bilateral normal vision; 17 per cent having normal vision in one eye with the other defective. The highest percentage of defective vision was in the workers who made the greatest use of their eyes and upon whose eyes the maximum strains might come. The Life Extension Institute examined 675 employees in the Underwood Typewriter Company, these individuals being engaged in close work demanding discrimination of detail, and found that 58 per cent were in need of ocular corrections. An examination of the vision of 3000 employees of the

Robert Gair Company of Brooklyn gave the following results: 22 per cent normal, 30 per cent astigmatic, 28 per cent hyperopic and 7 per cent myopic.

These results will vary somewhat depending upon the basis of the examination and the method of testing. In most of these reports we have no details as to the methods of examination pursued. We believe that retinoscopic findings should form the basis for the determination of the actual error present and hence should form the basis of the determination of percentages of normal and abnormal eyes from the physical side. From the physiological side, the criteria of normal acuity and reflexes would doubtless form the best basis for records of normal and abnormal.

In the department of health of the American Optical Company, all records for the year 1921 were made upon the basis of the retinoscopic disclosures. These records show that the following conditions obtained: (1) Persons under 40 years: new applicants 77.7 per cent abnormal or defective; routine department 78.2 per cent; defective amongst those requesting examination, 94.5 per cent; (2) Persons over 40 years: new applicants 88.8 per cent abnormal or defective; routine department, 90 per cent; defective amongst requested examinations, 93 per cent. The records show some extremely interesting conclusions on the percentage abnormal cases on a one diopter lens correction, best eye; this one diopter correction covering both spherical and cylindrical elements. (1) Persons under 40 years; new applicants 24 per cent, routine department 25.8 per cent, requested examinations 37.5 per cent. (2) For persons over fifty years of age these percentages ran 45.4, 44.5 and 45.8 respectively.

Problems of illumination go hand in hand with the relationship of eyestrain and eye defects to industry. Eyes, even if normal, work inefficiently under either too much light, too little light, too marked contrast or too weak contrast. A recent investigation of the lighting in over

four hundred factories has been completed and these reports show that 8.7 per cent are excellent, 32 per cent good, 29 per cent fair and nearly 20 per cent poor. The questions of the use of daylight and translucent screens; direct, indirect and semi-indirect artificial lighting; the use of north exposure; the placing of machines; these and a multitude of others similar to them are of vital importance to human efficiency and comfort and the maximum quantity and quality output.

Syphilis and the Eye

being

An Address Delivered in Minnesota*

Thomas Hall Shastid, A.B., A.M., M.D., LL.B., F.A.C.S.

WHEN I received the kind invitation of your president to speak before you, I thought at first that I would address you extemporaneously—many listeners, as I know, very much preferring that particular form of address. But after I had chosen my subject and had pondered for some time on its great possibilities, I thought I had better write the matter out, for, in that way, I should be best enabled to lay before you the utmost possible number of points in the shortest possible space of time.

Now syphilis (otherwise known as the French disease, the pock, the rust, and the bad disorder) has lately increased, especially in Minnesota and Wisconsin, at a most alarming rate. Three or four years ago, statistics told us that, at the time, in Minnesota, every tenth person had syphilis. I never could quite believe the figures. Yet they may have been correct. If correct, then every other family in this state was, on the average, cursed with a case of syphilis. The condition must be even worse at the present time. In fact I was told, only a day or two ago, by a very reliable general practitioner, that, in a considerable number of rather large Duluth families, every single member had syphilis. A specialist on genito-urinary diseases, practising here at the Head-of-the-Lakes, informed me, a year or two ago, that for a long time not a single week had passed but some little girl, below the age of puberty, had been brought to him suffering, as a rule, from both syphilis and gonorrhoea. The gonorrhoea was bad enough. Inherited syphilis would have been a calamity, but still quite credible. But what shall we think

* Read before the Head-of-the-Lakes Association of Optometrists Nov. 8 1921.

when a man of unquestionable veracity, who is making a speciality of sexual disease, informs us in a matter of fact tone, that, for a very long time, not a single week had passed without some little girl, below the age of puberty, being brought before him, suffering not merely from gonorrhoea but also from syphilis, and from both of these terrible diseases in the acquired form. Of course, there is no inherited form of gonorrhoea. Some years ago I noticed in the statistics for the Southern Illinois Hospital for the Insane at Anna, Illinois, that 51 per cent of the insanity in that institution was due to syphilis, either inherited or acquired.

So you see, gentlemen, the great importance of syphilis in a general way. And when you consider, as you certainly must if you care for the truth, that practically all syphilitics sooner or later suffer from syphilis of one or another structure in the eye, and that these eye affections are every day complicating the work of the refractionist, you will not, I think, wonder that I have chosen to speak to you this evening on the all-absorbing topic of the eye in syphilis.

First of all, What is syphilis in general? If we don't consider that subject, at least very briefly, then we shall not at all understand the ocular complications of the disease. Now syphilis is not necessarily (although it is usually) a sexual disease. It is simply a contagious disease, produced by a microscopic animal called the *spirochaeta pallida*. The disease does not "strike through the air." The tiny, microscopic animal must be conveyed from a person who already has syphilis to another who has it not, in order that the second person may become syphilitic. The conveyance, however, need not be direct. It may be indirect. If a person with syphilis, who happens to have syphilitic sores in his mouth, kisses a person who is without syphilis, and the latter (as he is quite likely to do) contracts syphilis, that is a direct conveyance of the disease. But if the same person, with syphilitic sores in his mouth, puts in his mouth a spoon, or drinks from a cup, and then another person comes along

and uses the same cup or spoon, before it is thoroughly cleansed, then again the second person could become infected. That would be indirect conveyance. There is not quite so much danger of an indirect, as of a direct, conveyance, because the microscopic animals on the cup or spoon have a chance to get chilled, betwixt person and person, and so to have their activity, or infectiousness, destroyed. It was because of the many cases of syphilis which had been directly contracted through kissing, that doctors, a number of years ago, instituted a kind of crusade against promiscuous kissing. It was, on the other hand, because of the frequent occurrence of indirect infection that the use of common drinking cups was abolished by law from railway stations and trains and from many other places. Of course, bad men and bad women, as is well known, are the chief causes of acquired syphilis.

But syphilis may be inherited, as well as acquired. And the inherited form does not respond to treatment anything like so well as the acquired form. Frequently the child dies before it grows up. Sometimes it even dies before it is born, being then what is called "a still birth." I should add that still births often occur from other causes than syphilis. Syphilis can be contracted from a person suffering with inherited syphilis just the same as from a person suffering with acquired syphilis. It is all the same disease. Again, a child of syphilitic parents may be born without syphilis, and then get the disease from a parental kiss or other contact.

When a person who is free from syphilis becomes infected with the germ of syphilis, a sore appears at the place on the body where the infection occurred. The length of time elapsing between the infection and the appearance of the sore is, as a rule, from three to five weeks. The sore is called the "chancre." It constitutes the first stage of syphilis. Early in this, the first, stage, the disease is still purely local, and, if injections of salvarsan (606) or the like,

are given at this time, the disease is frequently aborted, and the secondary and tertiary stages of syphilis (the constitutional stages) never occur. As a rule, however, owing to a foolish shame, the patient procrastinates, and does not present himself to his physician until the lymphatic vessels have sucked up the virus from the local sore and distributed it all over the body. The patient then always goes through the so-called "secondary" stage. Some patients, if not vigorously treated at this time, go also through what is called the "tertiary stage." The secondary stage is the stage of the more superficial skin eruptions, of sore throat and mouth, of headache, falling of the hair, fever, iritis, and many other symptoms too numerous to mention. Blindness, or great impairment of the vision, not infrequently occurs at this stage in consequence of the iritis. A point to remember about both the secondary and tertiary stages is that no two persons ever go through these stages in exactly the same way. One patient may never have headache or fever, and yet may have a tremendous case of skin eruptions. Yet another will have his skin eruptions so lightly that he never notices them, and yet will have a tremendous case of iritis. And so on.

In the tertiary stage the affection strikes deeper. It attacks the heart, the arteries, the septum of the nose, the choroid coat of the eye, the vitreous humor, the retina and optic nerve, the brain, the spinal cord. Once again, remember that the symptoms of syphilis are hundreds in number, and the possible combinations of symptoms and intensities of symptoms are simply infinite. You know that the English language, by combining and re-combining, a few at a time, the twenty-six letters of its alphabet, produces all of its more than a hundred thousand words. And then there are many other languages using substantially the same alphabet. But in syphilis, there are more than twenty-six symptoms, more by far. So you see how it comes about that "no two persons ever have, or can have, syphilis alike."

Yet the skillful physician, as a rule, knows syphilis when he sees it. No two negroes look alike, and yet you know a negro when you see one.

There is also another stage of syphilis, after the tertiary stage. It is called "the parasyphilitic state." In this stage belong many deeply-seated nervous disorders, chief among which is the well known "locomotor ataxia," in which affection, by the way, there appear numerous and serious eye-symptoms.

And now we come to a systematic presentation of the eye symptoms of syphilis. Of course you understand that syphilis of the eye, if considered at length, would fill a volume of a thousand pages or more. Let us, however, tonight, attempt to sketch out briefly the salient features of the ocular complications of this many-formed disease. We will take up first the anterior structures of the eye, and then pass to the deeper structures.

First of all, a chancre (which, as I have said, is the primary stage of syphilis) may appear upon the eyelids, and either upon the skin or the conjunctival surface. It sometimes, though rarely, is found upon the cornea. Of course, a chancre occurs upon whatever part of the body happens to have been infected. The possibility of absolutely aborting the disease in this stage makes the diagnosis at this time exceedingly desirable.

Madarosis (falling of the eyelashes) is not infrequently due to secondary or tertiary syphilis. As a rule it is not syphilitic. It may be non-syphilitic even in a syphilitic person.

The papular syphilide and copper-colored patches occur on the skin of the eyelids, just as on other portions of the body, in secondary syphilis. In the same stage occur also mucous patches in the conjunctiva. Mucous patches, by the way, are about the most contagious lesion of syphilis. They are tiny whitish, or grayish, ulcers (mere little patches of paleness) appearing on any of the mucous surfaces of the

body—the lips, the inside of the nose, the conjunctiva, etc.

Gumma of the lids occurs in the tertiary stage. The lid becomes swollen and tense, and, if vigorous antisyphilitic treatment is not promptly instituted, the lid may slough.

Stoppage of the tear ducts is very often due to syphilis. There is running over of tears, especially in a cold wind. After a time the lacrymal sac inflames and suppurates, with or without a fistula forming to the surface of the skin. All these lacrymal troubles may be due to other causes than syphilis.

The chief syphilitic affection of the cornea is interstitial, or parenchymatous, keratitis. There are two forms of this affection. In the first form a whitish ring appears, all round the cornea at its very circumference. This ring of whiteness proceeds to spread until it has reached the center of the cornea, when the whole cornea is, of course, white, and the patient is therefore blind. In the other form, the whiteness appears first in the center of the cornea, and thence spreads to the circumference. Both eyes are, as a rule, affected, but one eye generally before the other. In either form of the disease, the patient often becomes blind, unless treated soon and vigorously. This affection—interstitial keratitis— occurs almost always in children suffering from hereditary syphilis. Accompanying interstitial keratitis we nearly always have inflammation of the internal ear (labyrinthitis) and Hutchinson's teeth. Hutchinson's teeth are simply the upper, central incisor teeth of the second, or permanent, set, which, at their articular extremities, show not a straight edge but a semilunar notch.

Syphilitic iritis is one of the commonest and yet one of the most serious affections of the eye. The chief symptoms are: redness of the sclera round the corneal margin, turbidity of the aqueous, change of color in the iris, myosis, *i. e.*, abnormal smallness of the pupil, a sluggish pupillary light-reflex, impairment of vision, and pain. The chief danger is that adhesions will form between the back surface of the iris and

the front surface of the lens. The iris is normally in contact with the lens at its pupillary edge, and, when inflammed, the iris pours out adhesive lymph. This lymph organizes, and, wherever the iris and the lens are in contact, it glues the two together. Then the patient, even if he gets well of his iritis, has a sensitive eye for life, for every time the iris by contracting or expanding seeks to adjust the eye to varying intensities of light, the adhesions between the iris and the lens are pulled upon and the result is pain and irritation. The early use of atropin, by dilating the pupil, keeps the iris where it cannot come in contact with the lens. Then, when the disease has been cured, the pupil can be allowed to resume its normal size with safety. The various complications resulting from untreated, or improperly treated, iritis, I have no time to speak of. I wish to say, however, at this point, that, though syphilis is, in many persons, incurable so far as the latent poison is concerned, practically all the manifestations of syphilis are easily curable, if taken in time. Hardly anyone need be damaged by his syphilis if he watches himself carefully for its various manifestations.

A gumma sometimes forms on the front surface of the iris in tertiary syphilis. When this heals, it leaves a tiny red spot, very significant indeed to those accustomed to remark it.

Syphilitic hyalitis, *i. e.*, inflammation of the vitreous body, is not uncommon. It is frequently overlooked, the examiner only feeling that, for some vague reason, he is not getting a clear view of the fundus with his ophthalmoscope. Get away from the eye about fourteen inches, move a few degrees to the temporal side, and use parallel rays. Then you can see that the vitreous is turbid. Syphilis, however, is only one of the causes of hyalitis.

Nearly always present with syphilitic hyalitis is syphilitic choroiditis, or choro-retinitis. The patient sees flashes of light, and often perceives whatever he looks at as either too large or too small (macropsia and micropsia). The retina

is hazy because of swelling. The retinal pigment often disappears over large areas, and then the choroidal vessels come distinctly into view. Often there are large splotches of exudate in the choroid. Oftener, however, there are minute spots, or foci, of exudation all over the choroid. Then we have the well known *disseminate choroiditis.* When the exudate absorbs, each spot where the exudate lay becomes atrophic and white, but bordered with a black ring, or mass, of pigment. The appearance is very characteristic.

Syphilitic retinitis occurs in the following forms: the diffuse syphilitic retinitis of Jacobson, relapsing syphilitic central retinitis, syphilitic hemorrhagic retinitis, syphilitic arteritis of the retina and syphilitic perivasculitis of the retina, retinitis proliferans and retinitis pigmentosa. I have only time to describe the appearances in the last two of these various forms of syphilitic retinitis. In retinitis proliferans dense masses of whitish connective tissue, taking their origin from the retina, grow out into the vitreous a considerable distance. The look of these masses is very characteristic, and, once noted, is never forgotten. Retinitis pigmentosa is also a very peculiar disease. Sometimes it seems to be due to consanguinity of the parents, without syphilis. Generally, it is caused by hereditary syphilis. Night-blindness is a striking feature: the patient may see fairly well in the day time, but, as evening comes on, he can hardly see at all. The field of vision is also contracted, so that school-children afflicted with this disease, often read their school books well enough, because their central vision is good and yet cannot possibly find their way home unassisted. The retina is found, in well advanced cases, to be of a grayish, or grayish yellow, color, and to be sown in the equatorial region with numerous small, irregular pigment spots, about the shape and apparent size of copper jackstones. The blood-vessels are contracted and reduced in number. Sometimes indeed they are mere threads, with hardly a passage inside them. These patients generally become afflicted in child-

hood, and, in middle life, go blind. In fact I hardly know any more pitiful illustration of the principle that the sins (sometimes also the accidents) of the parents are visited on the children, than retinitis pigmentosa.

Syphilis of the optic nerve is very common. In fact one-third of all the cases of optic neuritis are due to syphilis. The head of the optic nerve is swelled and projects beyond the retina. The retina near the nerve is corrugated, thrown into folds. The vessels are always tortuous, and there are often hemorrhages. The disease may be acute or chronic, and the nerve may be affected in any portion of its course, or throughout its entirety. Treatment has to be begun early and pushed with great vigor. Otherwise the sight is generally lost, by atrophy of the nerve. There are scores of persons in Duluth, blind on one side from syphilitic atrophy of one or the other optic nerve.

Gumma of the optic chiasm, with resulting hemianopsias and various other sorts of visual troubles, as well as syphilitic affections of the central nervous apparatus is so vast a subject that I dare not trench upon it here. The same thing is true of syphilitic paresis and paralysis of the various ocular muscles, and the various ocular affections heralding or complicating locomotor ataxia. I may, however, observe that, when a patient is suffering from a syphilitic weakness of any of the ocular muscles, he needs not prisms or muscle training, but vigorous anti-syphilitic treatment instituted soon enough to prevent the weakness from passing into complete and incurable paralysis. I may also mention that paralysis, partial or complete, of the ciliary muscle, is not infrequently due to syphilis, and that it is often then mistaken for hypermetropia or presbyopia.

Gentlemen, next to errors of refraction, syphilis is the most important affection of the eye. And syphilis often complicates errors of refraction. I have spoken to you at considerable length—at too great length perhaps—and yet I have given but the barest outline, a mere sketch or hint, of

the subject. I hope that no one present will think that I believe myself to have presented a real exposition of the almost illimitable subject of syphilis.

I also hope, in conclusion, that, being men as well as scientists, we shall feel it our duty, whenever we have occasion, to warn, protect and guard the laity against the dangers of syphilis. Syphilitic children are not born into the world, they are cursed into it. It is bad enough for a guilty man or woman to suffer from this terrible disease. But what shall we say of an innocent child, whose whole life is blasted merely because of the lust of one or the other of its parents? For the innocent, gentlemen, for the innocent as well as for the guilty, the wages of sin is, as always since the beginning of time, sickness, pain, inefficiency, blindness, insanity, death.

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Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

Samuel H. Robinson, O.D., F.O.S.

CHAPTER II

The Phoria or Muscle Tests

The Diagnostic Steps in Muscle Work

WITH every case of muscle work that presents itself, two essential preliminary steps are necessary which, when investigated, will afford a comprehensive outline of the case, making it possible, should muscle treatment be necessary, to correctly and intelligently pursue the work. These first steps become an important form of diagnosis.

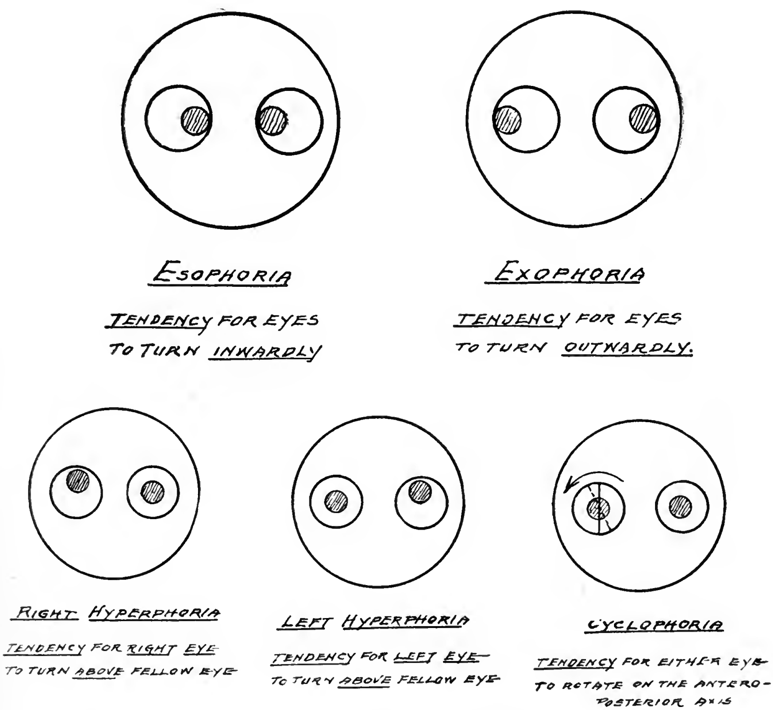
I. It must be determined if the eye muscles are in a state of balance; should there be an imbalance, its nature and degree must be ascertained. This is called *muscle testing for imbalance* or the *phoria tests*, and the several *prominent* forms as commonly observed are designated:

1 *Esophoria* (eyes having a tendency to turn *in*, Fig. 8).
2 *Exophoria* (eyes having a tendency to turn *out*, Fig. 9).
3 *Right Hyperphoria* (right eye having a tendency to turn *up* and above its fellow eye, Fig. 10).
4 *Left Hyperphoria* (left eye having a tendency to turn *up* and above its fellow eye, Fig. 11).
5 *Cyclophoria* (a tendency for either or both eyes to turn *upon the visual axis*, Fig. 12).

II. Whether we find a condition of muscular equilibrium or one of imbalance we should always determine the exact *duction* or *pulling power* of each of the several pairs of eye muscles in order to ascertain more definitely which, if any, of such muscles, require exercise and to what extent, if necessary, such exercise shall be administered.

These tests are known as *duction tests*. Eye muscles when *normal* should hold or withstand as a rule the following prism power:

a The *internal muscles* (together) *24 degrees* of prism power. This power is designated *adduction* (Fig. 13).
b The *external muscles* (together) *8 degrees* of prism power. This power is designated *abduction* (Fig. 14).
c The *upper muscles* (each eye separately) *2 to 3 degrees* of prism power. This power is designated *supraduction*.
d The *lower muscles* (each eye separately) about *3 degrees* of prism power. This power is designated *infraduction*.



Figs. 8, 9, 10, 11, 12. Illustrating various tendencies to binocular incoördination.

e When prism power is placed over one eye (*apex up*) to make its *upper muscle* pull it *up*, it is equivalent to placing that amount of prism power over the other eye (*apex down*) to make its *lower muscle* pull it *down*,

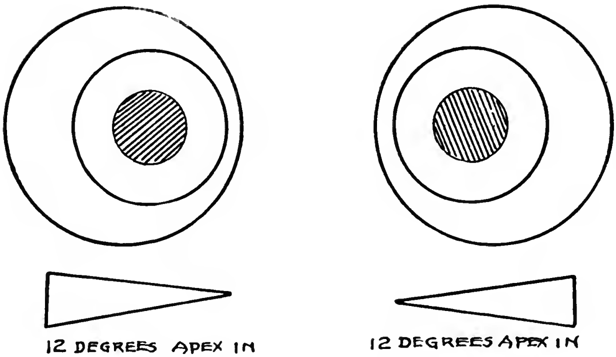


Fig. 13. Adduction.

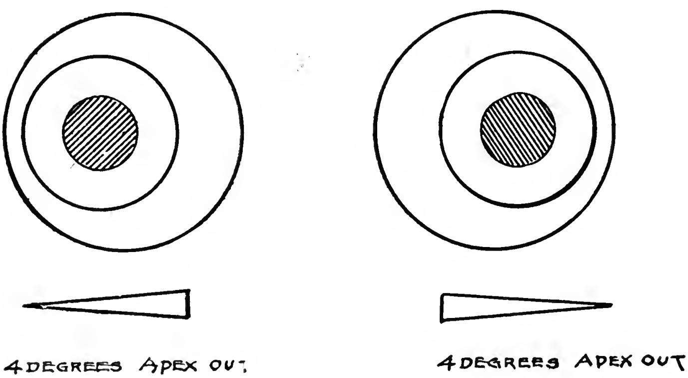


Fig. 14. Abduction.

and vice versa. Hence, in testing the vertical muscles, when you place prism power over one eye muscle you are also bringing into action (in a contrary pull) the opposite muscle of the other eye. All vertical

tests, therefore, register the combined power of the upper muscle of one eye and the lower muscle of the other, or vice versa.

This combined power is designated *sursumduction* and when normal should measure 4 to 6 degrees of prism power. (Fig. 15.)

Muscle and Duction Tests a Valuable Diagnosis

After determining the *muscle balance* and the *duction power* of the extrinsic muscles, the operator will then have the proper data at hand by which the weak muscles and their degree of impairment are known to him. The investigations into the ocular muscle conditions so far represent the diagnostic portion of the work, after which the refractionist may proceed in a most definite and intelligent manner with the *muscle exercise*, the ultimate and decisive portion of oculo-prism work.

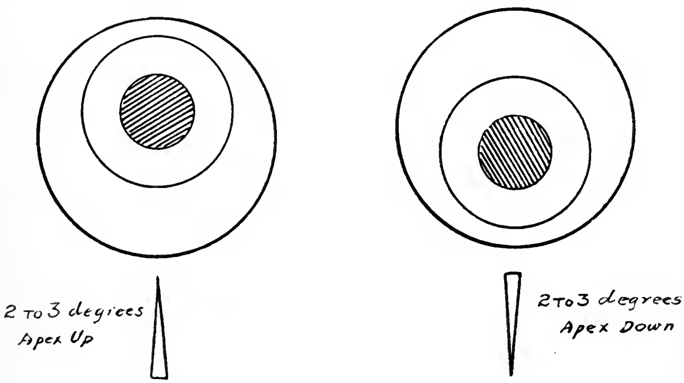


Fig. 15. Sursumduction.

Principles Involved in Muscle Tests

The principles underlying muscle testing are generally well known but for the refractionist who has not yet made

muscle work a part of his regular practice, indecision and confusion attend every scattered attempt to perform such work. The difficulty in the past has been that in the chain of facts pertaining to ocular muscle work so many links have been missing that the operator at no time had a consecutively logical knowledge which would enable him to enter upon and consummate a muscle problem intelligently. The fault has been partly in the type of literature available and partly in the individual practitioner. Texts written upon ocular muscles have on the whole been accurate and helpful but adapted preferably for school use, to be studied under the guidance and help of an instructor. Few men occupied with the various details of a refracting office have found the time or could muster the effort to extricate from complex and technical literature the complete chain of information necessary to engage in practical muscle work. The result has been that the few facts that had been previously gleaned have lost in their detached form any semblance of practicability and in due time have become but rambling memories, too vague for any practical use.

In this work every optical fact and principle is intended to be made so plain and understandable, even at the expense of tedious repetition and elaboration, that the conscientious student will in conclusion have a definite and intimate concept of what muscle work portends. The successive steps pursuant to this work will appear logically interdependent and so workable along practical lines that the mind can easily grasp and understand them as the work progresses. With that sort of a working knowledge an operator will seldom feel lost and a higher degree of interest and confidence will have been established.

Two Kinds of Knowledge Valuable in Muscle Work

In doing ocular muscle work two kinds of knowledge are valuable. One covers the fundamental principles governing

each step, the other is a specific working method for accomplishing it. In the matter which follows general principles will be outlined and specific forms of procedure such as the writer generally employs will be indicated in order that the reader may have a definite system he can adopt permanently in his work. Those who already have methods of their own will, of course, use their own discretion by following the form that suits them best.

Of the different forms of muscle imbalance, exophoria (a tendency for the eyes to turn outwardly) will be found the most common. Next in frequency is esophoria (a tendency for the eyes to turn inwardly), and last in order due to its slightness in degree if not its infrequency are the vertical imbalances, right and left hyperphoria. These last muscular errors are especially significant, only when reaching a relatively fair degree (say from two to three degrees or over). Since the duction powers of the vertical muscles are comparatively low, that which would be a slight degree of imbalance in the lateral tests is sufficient to develop in vertical imbalances a most irritating condition, if diplopia in fact does not actually ensue.

Influence of Lens Correction on Muscle Imbalance

Muscle imbalances are often in part, if not wholly, corrected by the lens correction. On the other hand such imbalances are often increased and aggravated by the proper lens correction rather than reduced by it. This has proved an inexplicable stumbling block to those who know nothing of muscle work, and but slightly less difficult to those who have only a vague idea of principles involved.

It will possibly be recalled that the ciliary muscle, whose function is that of accommodation, and the internal recti muscles, whose service primarily is that of convergence, receive their nervous energy from the same source, the third cranial nerve, and work together in a sort of partnership or unison. For instance, as the ciliary increases the accom-

modation, the internal recti muscles produce greater convergence; and as the accommodation relaxes, the tendency to converge likewise diminishes.

What is Esophoria?—Lens Influence on Muscle Imbalance

A condition of esophoria is one in which the internal recti muscles are excessively stimulated to the extent that the eyes wish to turn inwardly beyond that necessary for accomplishing single binocular vision. As increased accommodation stimulates increased convergence, it may be expected that reducing the accommodation will similarly reduce the excessive convergence. Thus if a condition of hypermetropia or increased accommodation exists at the same time that excessive convergence or esophoria exists, as you correct or reduce with plus lenses the excessive accommodation you at the same time and in somewhat the same ratio reduce the excessive convergence of esophoria. From this we may conclude that esophoria is the ideal imbalance when a condition of hypermetropia exists, since correcting the hypermetropia with lenses also corrects in part or whole the existing esophoria.

On the other hand, should we find it necessary to reduce the plus value of the eye, *i. e.*, approach or enter the myopic field when esophoria is present, we cause the ciliary, which seeks to compensate for the diminishing plus value of the eye, to experience at least a stimulus towards accommodation, thereby inducing greater convergence through the internal muscles and increasing instead of reducing the esophoria that is present.

By such reasoning as well as clinical observation there have been determined the following conditions:

1 IDEAL MUSCLE IMBALANCES (Sometimes requiring muscle exercise).	Esophoria with Hypermetropia Exophoria with Myopia
2 MUSCLE IMBALANCES NOT IDEAL (Demanding a reduced correction, more generally muscle exercise or both).	Esophoria with Myopia Exophoria with Hypermetropia

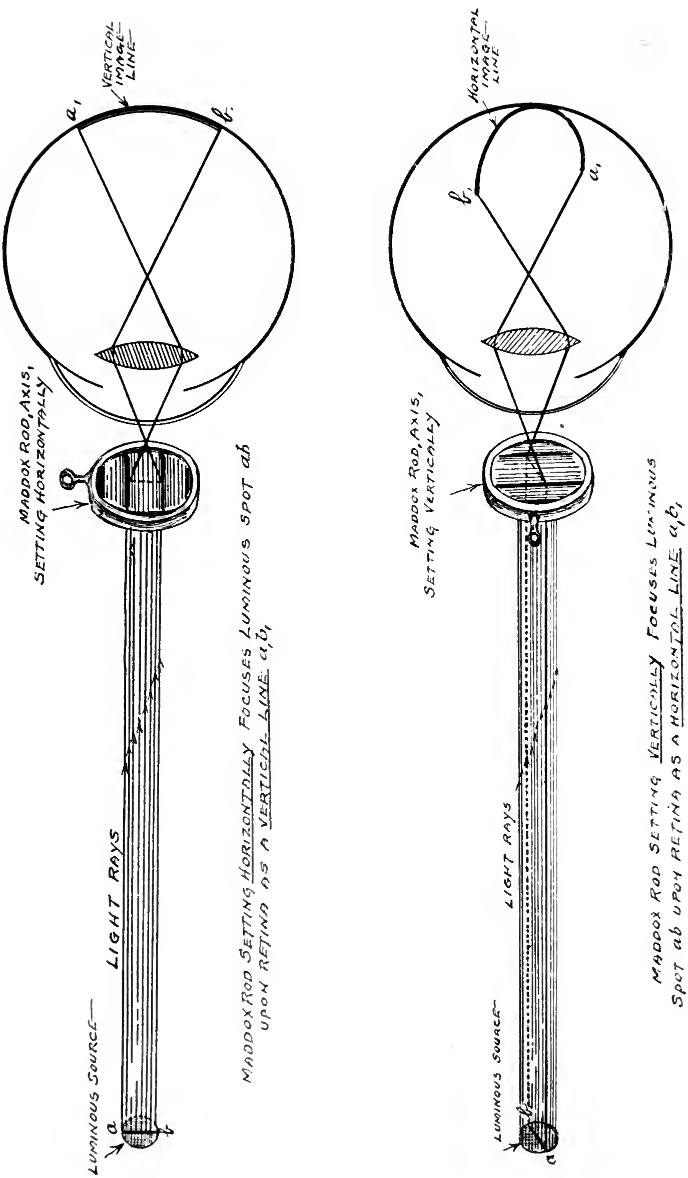
The last condition, exophoria with hypermetropia, seems to be the most prevalent.

Facts to be Recognized when Making Muscle Tests

Having summarized on the character of muscle imbalances, we are ready to proceed with the methods employed for testing the ocular muscles. In accomplishing this work the apparatus used consists of a Maddox rod (red preferably), a series of different power prisms, or a double rotary prism which may be adapted to any power necessary, a distant chart (at six meters) and test charts to be used at the reading distance. In making these tests the following facts must first be recognized.

1. The Fusion Sense

All persons possess in a greater or lesser degree what is known as a fusion sense or faculty, an inherent stimulation through the internal muscles, which assists the eyes in maintaining single binocular vision in spite of existing muscle imbalances. To uncover these latent imbalances incident to weak extrinsic eye muscles we must temporarily eliminate or destroy the element of *fusion*, after which the eye muscles may be expected to indicate their true tendencies and the eyes will roam in the direction guided by the resu'tant pull of all the muscles. The identical character of images situated on corresponding retinal points in both eyes helps support the fusion faculty. A distortion or change in character between the two images will tend to break up this fusion sense. In making muscle tests, therefore, we must shift or make dissimilar the images produced on both retinae. The most approved method is to change the image on one eye from, say, a luminous spot to a line or streak; a change in color is also desirable, offering a greater incentive towards image dissociation or nullification of the fusion sense. For this purpose we employ the red Maddox rod which converts a luminous white spot into a luminous



Figs. 16, 17. Testing for heterophoria with the Maddox rod.

red streak always at right angles to the axis of the Maddox rod. (Figures 16 and 17.) Thus, as the eye looking through the red Maddox rod beholds a red streak or line, the other eye which remains uncovered still sees the luminous white spot unchanged, and the radical difference in the two images destroys the stimulation towards blending or fusion and each eye begins to roam in a direction guided by the controlling muscles. In testing for esophoria or exophoria, it is the nature of the pull between the internal and external pairs of muscles in which we are interested. Thus, we study the position of the images as observed by both eyes, horizontally, and from the location of these images we determine which way the eyes have turned.

2. *How Objects Seem to Move with Respect to Rotation of the Eye, and Why*

Another fact we must learn before we proceed. *As an eye rotates in one direction, objects viewed always appear to move in an opposite direction.* The reason becomes very apparent. The position of objects in space is determined by the relative arrangement of their images on the retinae. Due to the inverted manner that objects are focused upon the retina, the upper portion of an object will focus on the lower portion of the retina and the lower portion of an object on the upper portion of the retina. The more remote a point is to the right of one's field of vision, the more remotely to the left of one's retina will that point be focused. Inversely, the more remotely to one side of the retina an image is focused the more remotely in the opposite direction, in space, must the object seem to be situated. As the image of an object is moved (by rotating the eye) from one portion of the retina to another the object in space will similarly appear to move but in a contrary direction. To illustrate, we will refer to Figure 18.

Looking at the arrow A B (the juncture of points A and B) which forms the image A_1 B_1 on the retina, we would say

that the point 'a' in space is located *above* the point A. Yet its image 'a_1' formed on the retina is *below* that of image A_1. Thus if the object point '*a*' really were not in space as designated but instead the eye were merely rotated so that the image point A_1 would move on the retina to the position

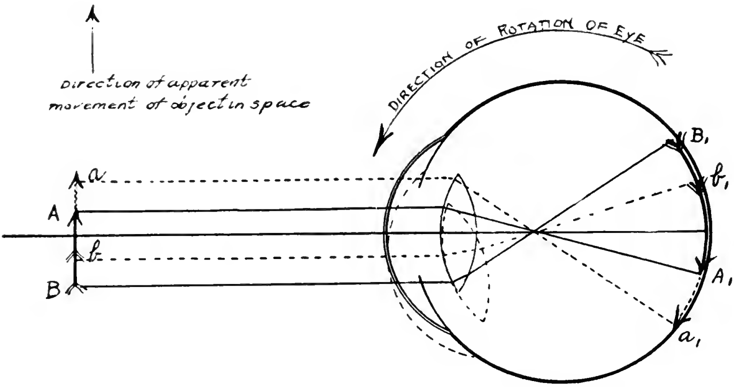


Fig. 18. Illustrating the relationship between ocular rotations and apparent movements of object in space.

'a_1' the object point A in space would likewise seem to move but in contrary direction until it occupied the position indicated by 'a' and A B would appear to have moved to the position 'a b.' We thus see the reason as well as ascertain the fact that objects in space always appear to move in the opposite direction from that in which the eye rotates. *This permits us in our tests to know in what direction the eye is turning or has turned from the direction in which the patient sees the object move or finds it displaced.* Such knowledge is both practical and fundamental and will assist us in understanding the logic and purpose of every step as we proceed in our work.

Testing for Esophoria and Exophoria—Principles Underlying

Returning now directly to the tests for esophoria and exophoria, we find that a red Maddox rod placed *horizontally* before, say, the *right eye* will make the white luminous spot appear to that eye as a *vertical red line;* while to the left eye which remains uncovered it is still the original white spot. Inasmuch as the images are very dissimilar, the tendency for the two to blend is so greatly disturbed that the natural pull of the muscles, uninfluenced now by the fusion sense, becomes manifest. We will remember that the *red vertical line* is seen by the right eye. Any movement of that line will indicate a rotation of that eye. Similarly a movement of the *white spot* will indicate a rotation of the left eye. Depending upon the direction in m6vement of these two images will be determined the direction of rotation of the two eyes. Should we find that the red line and white spot are together or intersect, there can be no lateral rotation of the eyes and a proper balance of the internal and external recti muscles must be in force, otherwise the images would have crossed or separated in proportion to the amount of imbalance present. Should the images cross, *i. e.*, should the *red line* belonging to the *right eye* appear to the *left* in the field of vision and the *white spot* belonging to the *left eye* appear to the *right* in the field of vision, we should conclude that the right eye has turned to the right (in contrary direction to the image) and the left eye to the left; and as both eyes have turned *outwardly* the condition of exophoria is thereby established. The degree of this imbalance alone would remain now to be determined. Similarly, had the *red line* belonging to the *right eye* appeared to the *right* of the field of vision, that eye would have turned to the *left*, or *inwardly*, and had the *white spot* belonging to the *left eye* appeared to the *left* of the field of vision, that eye would have turned to the *right*, or *inwardly*, and inasmuch as both eyes have turned *inwardly* the condition thereby expressed would be one of

esophoria, whose degree alone would now have to be established. (Figures 19 and 20.)

Determining the Amount of Imbalance in Esophoria and Exophoria

To determine the amount of esophoria or exophoria present, we need but recall these facts: In esophoria, under test, the eyes are turning *inwardly* and the images are *separated.* To determine the amount of esophoria or the extent to which the eyes have turned inwardly, we rotate sufficient prismatic power before both eyes, *apices inwardly*, to unite the images which have *separated* due to the inward rotation of the eyes. Thus we start with, say, one half degree prism, *apex in*, before each eye and continue increasing the power until the two images unite or intersect. The amount of prismatic power, *apices in*, thus necessary to unite the images will be a measure of the esophoria present.*

Similarly in measuring the amount of exophoria present we unite by means of prisms the images which have *crossed* due to the rotation of the eyes *outwardly*. In this case the prisms are set *apices outwardly* and increased in power until the images have been made to unite or intersect. The degrees necessary to combine or unite both images represent, when apices set inwardly, the amount of esophoria present and when apices set outwardly, the amount of exophoria present.

Testing for Right and Left Hyperphoria (Vertical Imbalances)

In testing for imbalance of the vertical muscles we set the Maddox rod before the eye with axis *vertical* so that the spot will appear as a *horizontal* red line. Inasmuch as we

* It must be remembered that objects or images in space appear to move in the direction of the *apex;* therefore, to shift images in space, prisms must be set before the eyes with *apices* in the direction they are to be shifted.

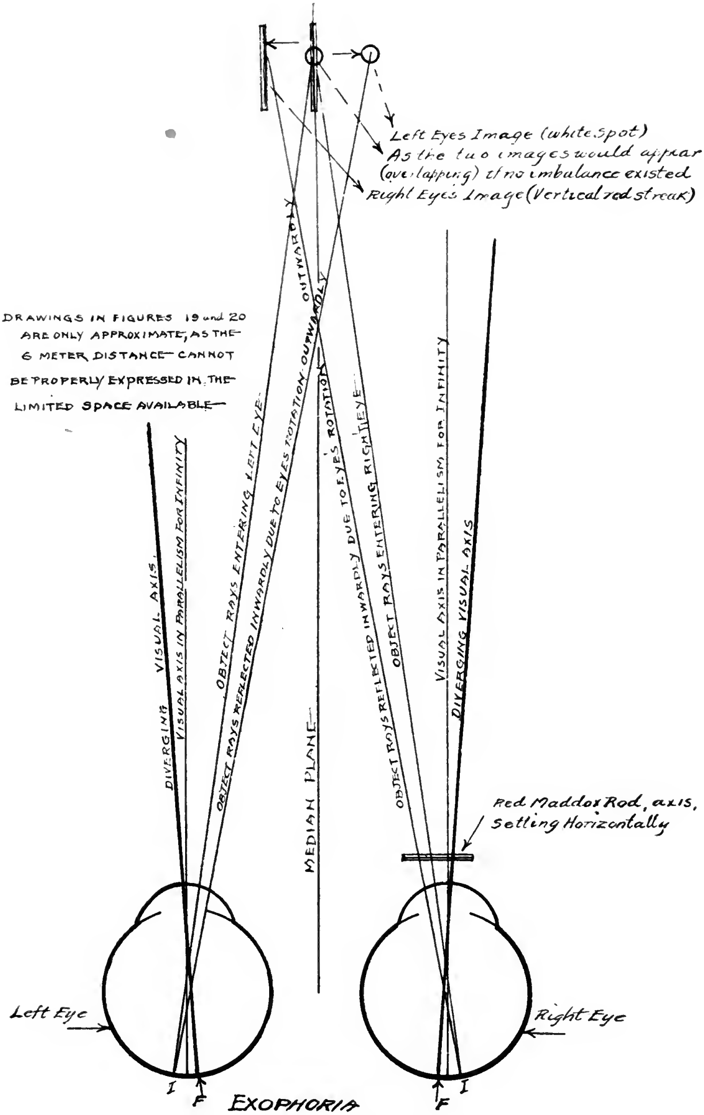


Fig. 19. Images seen in exophoria.

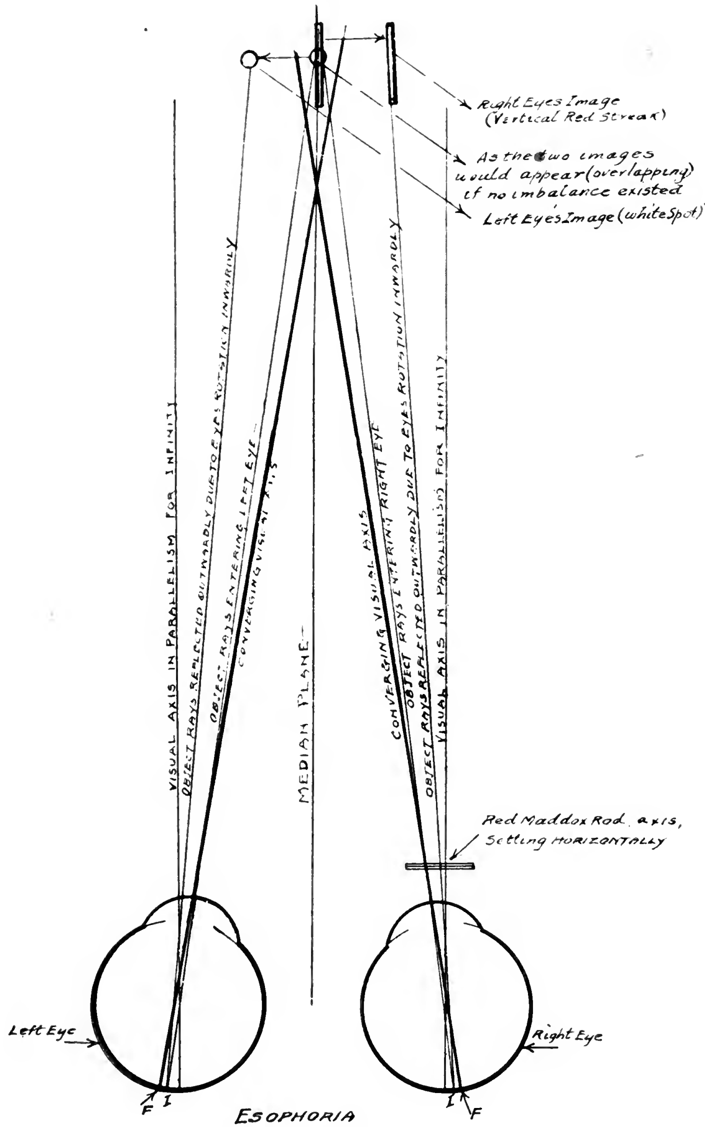


Fig. 20. Images seen in esophoria.

are dealing now with the vertical imbalance we must have one image a *horizontal* line so as to clearly discern when the other image (the white spot) is above or below it and thus determine the relative rotation of the two eyes vertically. Remembering that the *horizontal red line* belongs to the *right eye* and the *white spot* to the *left eye*, should we find the line below the white spot (Figure 21) then we may know that the *right eye* has *turned upwardly* above its fellow eye (since images move in the opposite direction

Fig. 21. Images seen in right hyperphoria.

from the rotation of the eye) and this condition is called right hyperphoria. Should the *white spot* be seen *below* the *line* (Figure 22) then we know that the *left eye* has

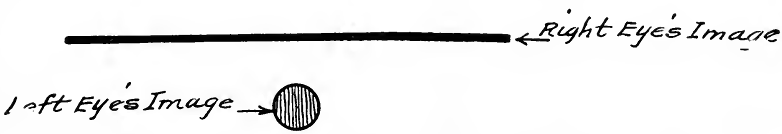


Fig. 22. Images seen in left hyperphoria.

turned upwardly above its fellow eye and the condition then would be denominated left hyperphoria. *Right hyperphoria* signifies that the *right eye* tends to turn *upwardly* while *left hyperphoria* indicates that the *left eye* tends to turn *upwardly*.

Determining the Amount of Imbalance in Hyperphoria

The amount of prism power necessary to bring the line and spot together in either case will measure respectively

the amount of right or left hyperphoria present. It should be remembered, as previously explained, that prism power, *apex up*, before one eye is the same as an equal amount of prism power, *apex down*, before the other eye and vice versa. In making tests for any muscle imbalance, the total prism power may be placed before either eye or distributed as desired between the two eyes but this distinction must be borne in mind:—whereas, in the lateral tests, the *apices* are placed over the *same muscles* of both eyes (*i. e.*, over both internals or externals), in the vertical tests the power when divided between the two eyes must be placed so that the *apices* will be over the *opposite muscles* (i. e., *apex up* over one eye and *apex down* over the other eye or vice versa).

Measuring Imbalances with the Stevens Phorometer

An instrument designed for rapid and accurate measurement of muscle imbalances is the Stevens phorometer, illustrated in Figures 22a and 22b. It consists of two circular prisms about 5 degrees each, mounted in cells which, geared to a small wheel W, revolve in opposite directions upon rotation of a handle H.

In testing for esophoria or exophoria, the prisms are set so that the *base* or *apex* of one is *up*, and that of the other *down*, while the indicator I points to zero upon a circular scale which expresses the degree of esophoria or exophoria. (See Figure 22a.) Looking at the luminous spot on the chart, two spots in a *vertical line* become visible under the diplopia produced by the prisms, when no lateral imbalance exists. In the event of a lateral imbalance, the spots are separated horizontally, *i. e.*, do not maintain a vertical line. The prisms are therefore rotated by means of the handle H, which produces the effect of placing prisms before the eyes, *apices in* or *out*, depending upon the direction of rotation. When the images have thus been aligned vertically, the lateral imbalance has been corrected and its measure

and kind will be expressed by the indicator I upon the scale marked esophoria and exophoria.

Similarly, when measuring right or left hyperphoria,

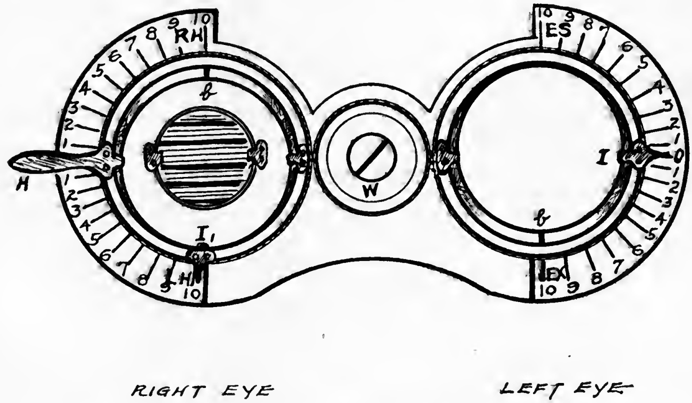


Fig. 22a. Stevens phorometer in esophoria or exophoria.

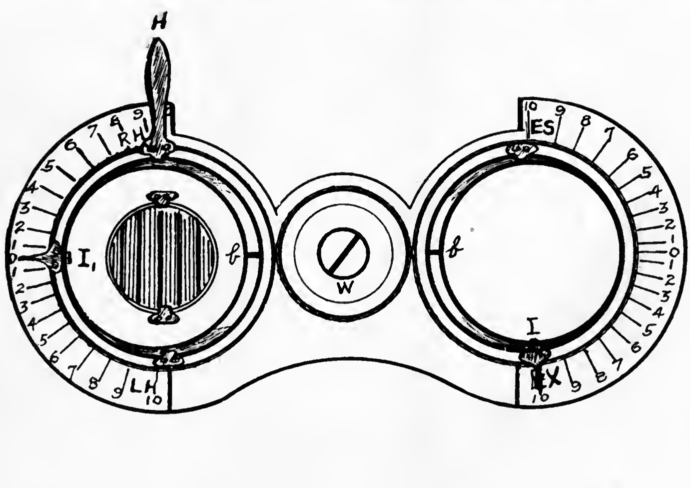


Fig. 22b. Stevens phorometer in right or left hyperphoria.

prisms are rotated so the *apices* set *outwardly* or *bases inwardly*, while the indicator I_1 points to zero upon the circular scale marked right hyperphoria and left hyperphoria. (See Figure 22b.) Lateral diplopia is thus produced, and any existing vertical imbalance becomes manifest, by the two images separating vertically, *i. e.*, by failing to maintain a horizontal straight line. Rotating the prisms until a horizontal alignment of the images takes place, corrects and measures the vertical imbalance, whose kind and degree are both expressed by the indicator I_1 upon the circular scale marked right hyperphoria and left hyperphoria.

While the above method is generally followed when using the phorometer, the author has found it simpler and more accurate to use in addition the red Maddox rod before the right or left eye, setting its *axis horizontally* when measuring the *lateral imbalances*, and *vertically*, when measuring the *vertical imbalances*. The advantages derived lie in the fact that a greater fusional dissociation is thus effected, and a more accurate alignment of images is made possible.

[To be continued]

Abstracts and Reviews

The Unaided Eye

James Weir French, D. Sc.

(This article contains much which is of the character of a résumé of fundamental anatomical and physiological facts with respect to the human eye. Some of these are of sufficient importance to bear repetition in this *Journal*. ED.)

Accommodation

OPHTHALMOMETRIC observations show that in the process of accommodation the anterior surface of the crystalline lens becomes more curved as the object approaches the eye and that over the greater part of the posterior surface facing the retina there is practically no change of curvature. As the anterior surface becomes more curved, the axial thickness of the lens increases while the equatorial diameter decreases. It is improbable that any change of volume of the lens itself is involved. The crystalline lens rests upon the vitreous humour from which it is separated by the posterior sac of the lens. This membrane which separates the aqueous humour entirely from the vitreous humour and thus the anterior chamber from the posterior, is practically an extension from the ora serrata of the hyaloid membrane which encloses the vitreous humour. The membrane is lettered 6 in Fig. 1, which shows the crystalline lens 3 and the meridional, radial, and circular muscles, 10, 11 and 12, that operate it in the act of focusing or accommodation.

It is generally agreed that the alterations of the crystalline lens are due to the action of the ciliary muscles, 10, 11 and 12, operating through the intermediary of the ciliary processes 9 and the suspensory ligaments or zonule of Zinn, 7, attached to the anterior and equatorial surface of the sac

containing the lens. There appear to be three sets of ciliary muscles, all of which play some part in the act of accommodation. The meridional muscles, numbered 10 in the illustration, as the name implies, lie in a meridional section of the eye. The circular muscles, numbered 12, lie in a plane normal to the axis of the eye and concentric with it. The

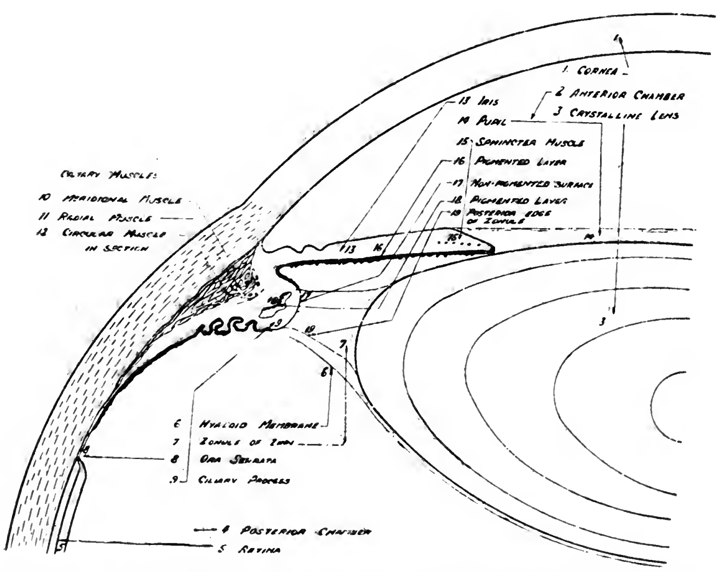


Fig. 1. The anatomy of the cornea, crystalline lens and ciliary bodies.

radial muscles, 11, occupy an intermediate position between these two sets, which they appear to bind together. From the ring of ciliary muscles about seventy projections called the ciliary processes, 9, extend radially inwards towards the crystalline lens to which they are connected through the intermediary of the zonule of Zinn, 7.

Now, although it is evident that all three sets of muscles take part in the process of accommodation, it is not clear

what their separate functions are. Considered generally, if the circular muscles 12 relax, the diameter of the ring carrying the ciliary processes will increase and exercise an equatorial pull on the crystalline lens that will tend to flatten its anterior surface. Conversely, if the circular muscles 12 contract, the diameter diminishes and the crystalline lens by reason of its elasticity when thus released recovers its previous curved form. It is certain that the action of accommodation is more complicated than the above very general account implies. The iris 13, for example, not only advances towards the cornea as the thickness of the crystalline lens increases, but the pupil 14 or aperture near its centre diminishes simultaneously in size. Around the pupil there will be observed a ring of muscle 15, called the sphincter muscle, which by contraction reduces the size of the pupil. There are also certain radial muscles which assist in the control of the iris. On the under side of the iris there is a dense black-pigmented non-transparent layer 16 which prevents any light from entering the eye except through the pupil. Similar pigmented layers will be observed on all those portions of the ciliary body through which stray light might possibly pass. The portions, 17, actually embraced by the zonule of Zinn are not thus protected but it will be observed that in front of them there are situated pigmented portions, 18.

Quite a considerable force is required to flatten the crystalline lens to its full extent and, considering the fineness of the membrane through which the force is transmitted, it is remarkable that it is capable of withstanding the pull without rupturing. No doubt this would be the case if the membrane were in the form of a plain annular ring connecting the ciliary body direct to the capsule of the lens. The difficulty appears to be overcome by the distribution of the total pull over a large surface, thus reducing the intensity. This will be more readily understood from an examination of Fig. 2 extracted from the *Physiologische Optik* of Helmholtz,

which represents a side, that is, equatorial, view of one quadrant of the lens. The vertical line *a*, *b* is the axis of the lens. The connection of the posterior surface of the capsule 6 in Fig. 1 is represented by the line *c*, *d*. Since the force of

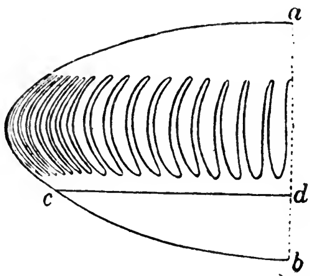


Fig. 2. Equatorial view of quadrant of the lens.
(From *Physiologische Optik*, Helmholtz.)

compression of the lens is resisted by the vitreous humour the tension in this membrane during the process of accommodation is probably negligible. The anterior membrane which is called the zonule of Zinn is folded somewhat like the ruffles worn around the neck of Elizabethan courtiers. Its point of attachment to the lens capsule is indicated by the wavy line of the illustration. To the anterior surface between the folds, of which there are approximately seventy, there are attached the separate ciliary processes 9, Fig. 1. Thus it will be seen that by this ingenious arrangement the pull is distributed over a large area and to the lens through a very great length of contact. In Fig. 1 the bottom of the fold is indicated by the line 19.

Between the folded line and the line *c*, *d* in Fig. 2, that is, between the zonule of Zinn and the posterior membrane, there is a space called the canal of Petit. This space is in communication with the anterior chamber of the eye through slits provided in the zonule and the space is accordingly filled with the aqueous humour. Thus the whole space from

the cornea to the membrane covering the vitreous humour is filled with the same liquid.

It should be observed that the iris only rests upon the crystalline lens at its central extremity, that is, around the pupil, and that the aqueous humour has access behind it and thence to the canal of Petit.

Although the volume of the crystalline lens does not alter during the act of accommodation, its change of form involves an alteration in the relative sizes of the portions of the anterior chamber in front of and behind the iris respectively. Since the total volume of the chamber remains unchanged or practically so, there must be a flow of liquid through the pupil from one side of the iris to the other. Helmholtz, however, considered it improbable that such a displacement could take place as rapidly as the action of accommodation requires, since the edge of the iris rests upon the lens, and he suggested that the adjustment was effected by a suitable movement of the ciliary parts around the base of the iris.

In altering the form of the crystalline lens the ciliary muscles exercise a considerable force which must be resisted by that portion of the wall of the eye to which the muscles are attached. But as the wall of the eye is not rigid, it would tend to yield under the pull of the ciliary muscles. Such a reduction of the equatorial diameter of the eye would involve a corresponding increase in the axial length since the eye is filled completely by the various humours, as was considered to be the case by Descartes. But it is accepted that no such changes of form occur. The reason is that inside the eye there is a pressure equivalent to from 20 to 30 millimetres of mercury. This pressure keeps the walls of the eye rigidly distended and enables them to resist the pull of the ciliary muscles. It is accordingly of the greatest importance in the dioptric function of the eye. Descartes' assumption previously referred to, that accommodation involved an axial variation of length, suggests that he was unaware of this intra-ocular pressure. The reason why there is liquid in

the anterior chamber will now be evident. Not only does it enable the crystalline lens to alter its form freely but it also, on account of its pressure, preserves the form of the walls of the eye and particularly the portion to which the retina is attached.

Effect on Pupil of Variation of Illumination

For the purpose of investigating the effect on the pupil of variations of the illumination, a telescope with an exit pupil of 0.5 inch diameter was used. The telescope was directed toward a collimator illuminated by a lamp, the intensity of which was varied by a flicker wheel. The

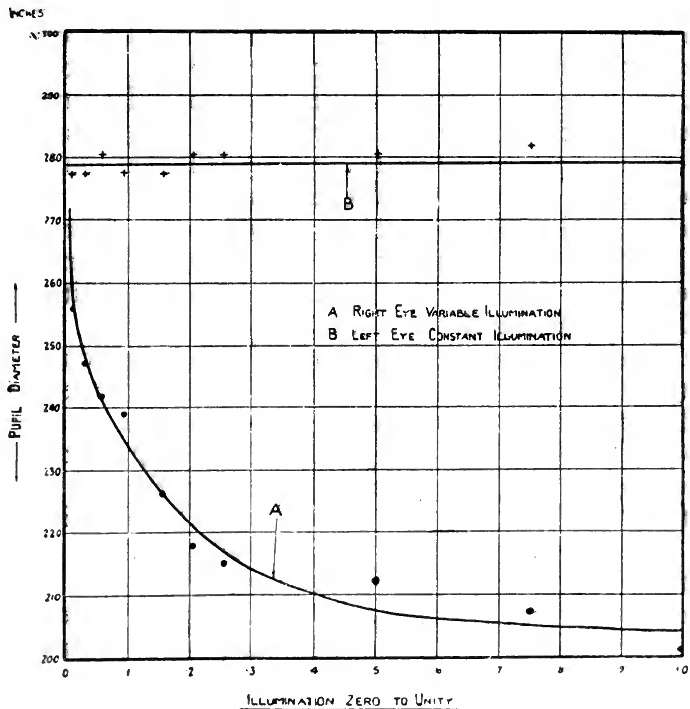


Fig. 3. Relations between illumination and pupil diameter.

question arises as to whether or not, if light is projected into one eye, the pupil of the other eye contracts also. From Figure 3 it is evident that the pupils may act independently. In this diagram the ordinates represent the diameter of the iris pupil and the abscissae the variation of the light from about zero to unity. Although the right iris pupil varied in diameter over a considerable range, as shown in curve *A*, the left iris pupil diameter remained nearly constant as shown in curve *B*.

Figure 4 indicates the variation of the pupils of the left eyes of two different observers as the illumination was varied by means of the flicker wheel. The abscissae represent the

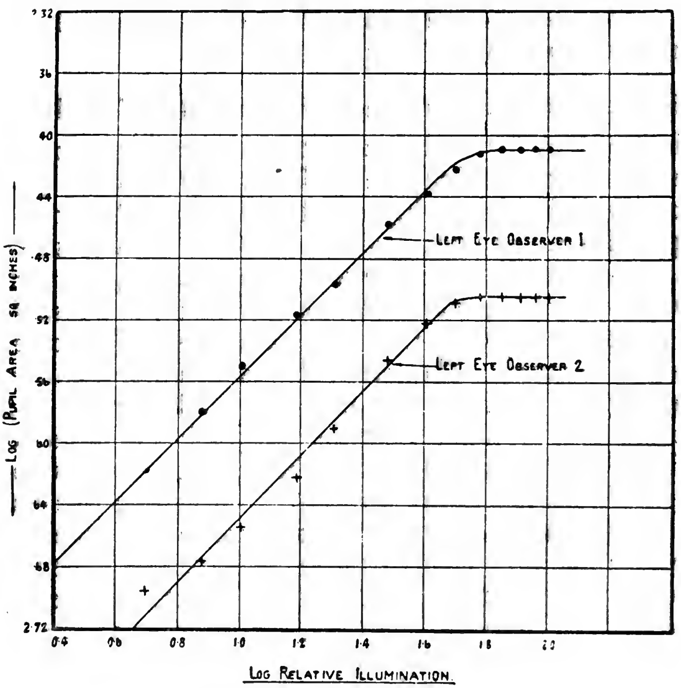


Fig. 4. Variation of pupils with illumination.

logarithms of the percentage illumination and the ordinates the logarithms of the corresponding pupil areas. When plotted logarithmically it is seen that the curve is practically a straight line over a considerable length. With small pupils the curve deviates from the straight lines, notwithstanding the fact that the illumination was only sufficiently great to close down the pupil to a diameter of about 0.18 inch, whereas the minimum diameter is about 0.08 inch. The straight line portion of the curve can be represented quite accurately by the expression: Area of pupil = K (Illumination)$^{1\cdot5}$. Hence, if the illumination is increased thirty-two fold, the pupil would contract to one-half its area. In all tests the angular field was about 5° and therefore the four curves indicate the sensitiveness of the macula lutea of the retina upon which the light fell.

Effects on Pupil of Illuminating Various Zones of the Retina

Similar data for various zones of the retina, concentric with the macula lutea, were obtained by means of the apparatus indicated in Fig. 5. Light from a "Pointolite" lamp was received upon a diffusing screen *A* from which it passed to a portion of a spherical glass screen *B*, one surface of which was fine-ground. When viewed by the observer's eye *C*, no variation of the illumination over the screen *B* could be detected. The screen *B* was of uniform thickness with an inner radius of 3.75 inches. A telescope *D* was so arranged that it could view the iris pupil and measure its vertical diameter upon a scale in the eyepiece. The amount of light falling upon the iris was in all cases sufficient to make it visible by means of the telescope. Immediately below the pupil there was arranged a horizontal scale which together with the pupil could be seen reflected in the small mirror *E* by the observer *C* himself, who was thus able in many of the experiments to obtain check measurements of the pupil diameter. The main purpose of the telescope *D* was to ensure that the position of the eye *C* relatively to the

mirror E was not altered. Any changes were easily detected by the observer at the telescope D. The central portion of the screen from (g) to (h) was painted black as well as the

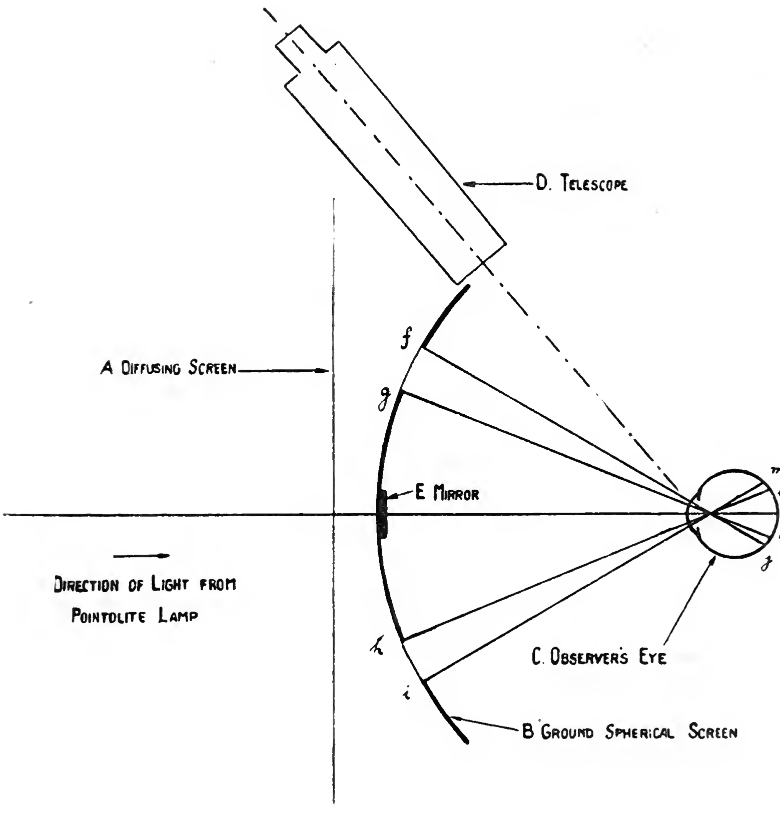


Fig. 5. Apparatus for illuminating various zones of the retina.

portion beyond (f) and (i) thus leaving a luminous ring or zone whose section is indicated by the lines (f, g) and (h, i). On the retina of the eye C there would then be formed a

corresponding image of the zone whose section is indicated by the lines (j, k) and (l, m). Substituting Helmholtz's schematic eye for the eye C of the observer, the widths of a series of retinal zones all of the same area were calculated and, knowing the position of the eye and the radius of the screen B, the widths and positions of the corresponding series of zones on B were determined. By suitably painting out the requisite portions of the screen B, any desired zone of the retina could be illuminated.

Since all the retinal zones were of equal area and the intensity of the illumination was maintained constant, the diameter of the pupil should remain constant if the sensi-

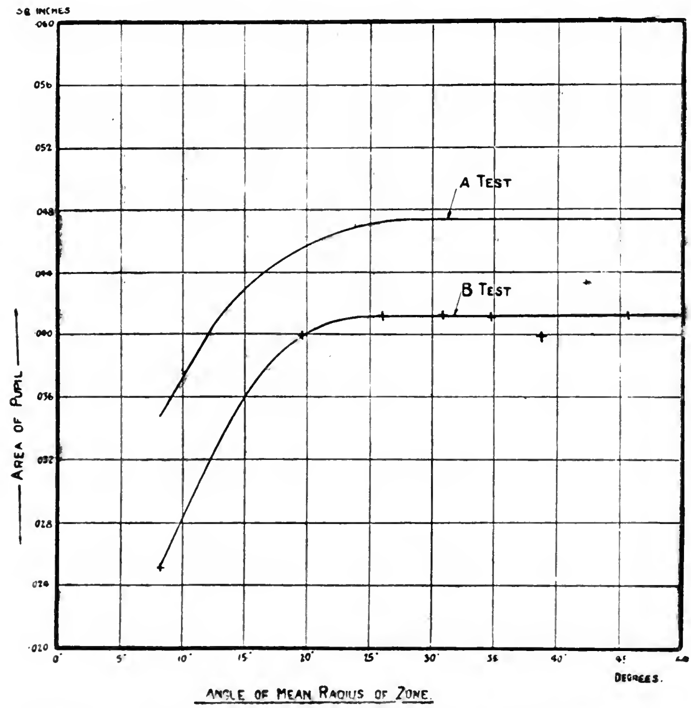


Fig. 6. Area of pupil — angle of mean radius of zone of retina.

tiveness of the retina to quantity of light were constant over all the zones. If, however, the retina was less sensitive over any particular zone, the pupil would expand so as to increase the quantity reaching each point and accordingly increase the total quantity of light distributed over the zone.

Figure 6 shows the results of two tests. The area of each zone of the retina was 0.06 square inches. Abscissae represent the angle subtended by the mean radius of the zone at the centre of curvature of the retina, not the nodal point of the Helmholtz schematic eye, and ordinates the area of the iris pupil. It will be seen that, as the distance of the zone from the macula lutea increases, the sensitiveness of the retina to light, so far as the iris reflexes are concerned, rapidly diminishes, and that at an angular distance of about 25° the sensitiveness has reached a minimum value. In the case of curve *B* it will be observed that the iris ceased to respond when the pupil diameter was considerably less than its maximum. From this and the previous Figs. 4 and 5 it would appear that it is the macula lutea and a comparatively limited portion of the retina around it that control the variations of the pupil diameter.

By means of the same apparatus the variation of the pupil area, as the intensity of the light reaching each of the retinal zones was varied, was determined by altering the distance from the screen of the "Pointolite" source and measuring the diameter of the pupil as before. As the intensity of the light varies inversely as the square of the distance D of the source, the abscissae in Fig. 7, which are proportional to $D^{-1/2}$, represent intensities of illumination. As before, the ordinates represent the pupil areas. Curve *A* indicates the pupil variations corresponding with the variable excitation of the zone immediately surrounding the macula lutea or yellow spot. The mean angular distance of the zone from the fovea centralis was 13.6°, as indicated on the diagram. This zone is particularly sensitive to variations of the light and evidently exercises an important

control over the pupil. As the intensity is increased, that is, as the illuminating source approaches, the pupil diameter rapidly diminishes and soon reaches a minimum value.

Curve *B* for a zone 20° from the fovea centralis shows that already the sensitiveness has become diminished very con-

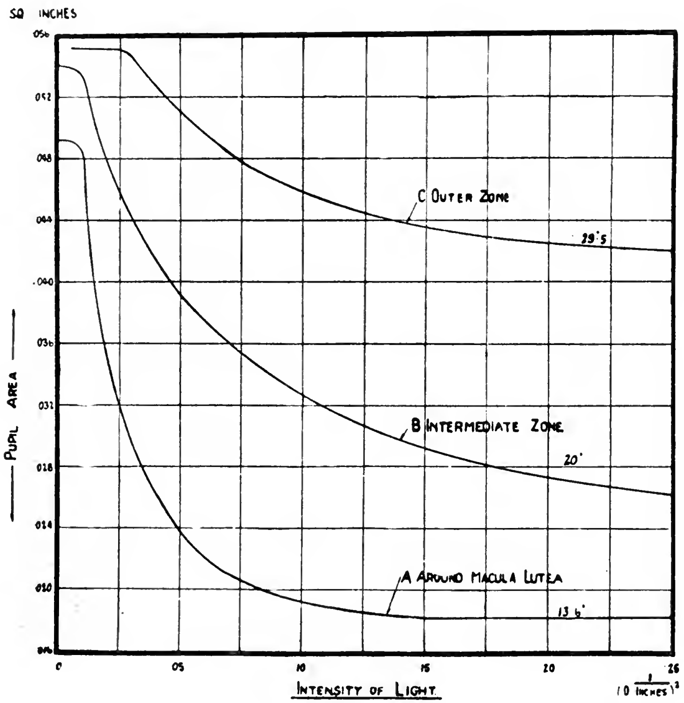


Fig. 7. Variations of pupil area with different intensities of zone illumination.

siderably. The pupil diameter diminishes at a much smaller rate and reaches a minimum value that is greater than in the case of the previous zone. Curve *C* for a zone 29.5° from the fovea centralis shows still greater insensitiveness. This portion of the retina requires all the light it can get and

the pupil opens out to nearly its maximum diameter and responds but little to the variation of the intensity.

Plotting logarithmically, it is found that the straight line portions can be expressed by the equation that the Area = K (Illumination)^x. For the zone nearest the macula the value of x is 1/3, for the intermediate zone 1/4, and for the outer zone 1/8. For the macula lutea itself the value of x is 1/5, hence it follows that, in so far as the iris reflexes are concerned the zones immediately surrounding the macula lutea are more important than the macula itself. The suggestion is offered that these results may help to explain why the existence of an indistinct object, but not its form, is best detected when its image falls just inside of the macula.

Pupillary Diameter during Accommodation

To determine the manner in which the pupil diameter varies during accommodation, an object the illumination of

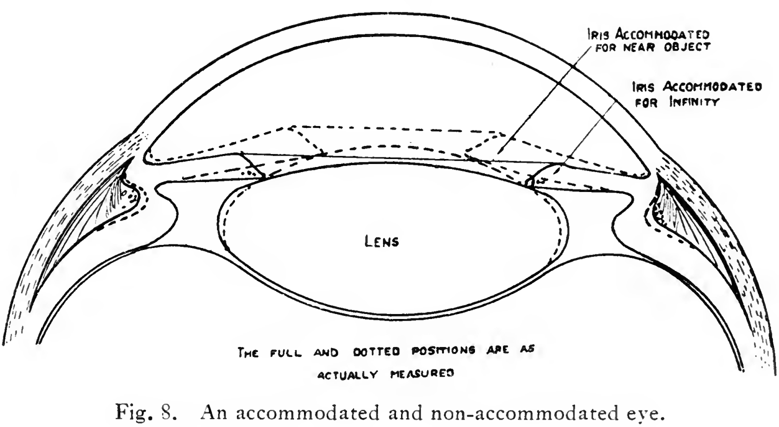


Fig. 8. An accommodated and non-accommodated eye.

which was maintained constant was made to approach the eye and the pupil diameter was measured for each position of the object. From the results plotted in curve I, Fig. 9,

it will be seen that no variation of the pupil takes place until the object is about 12 inches from the eye and that thereafter the contraction is very rapid. From a comparison with Fig. 7 it will be evident that the variation of the pupil during accommodation is not comparable with that due to a variation of the illumination which in any case was kept constant.

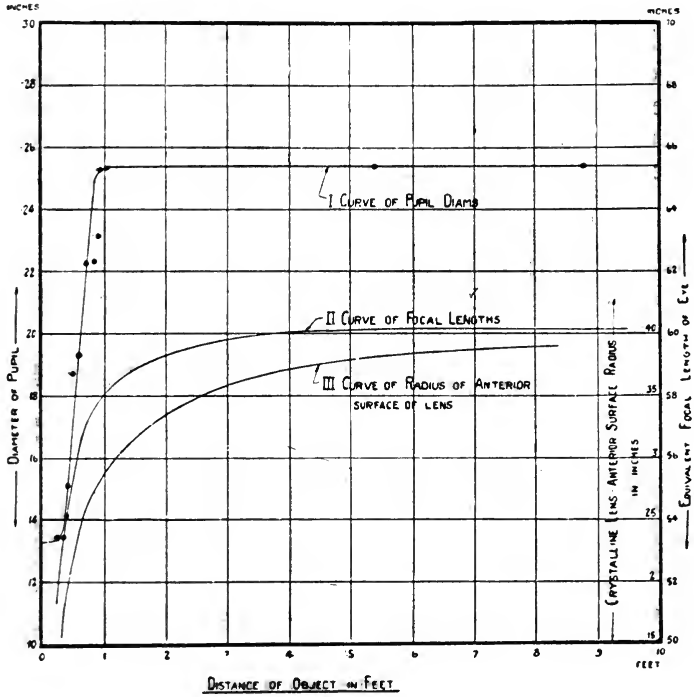


Fig. 9. Pupillary diameter during accommodation.

On the basis of the schematic eye, the focal lengths of the crystalline lens corresponding with the positions of the object were calculated. They are indicated by curve II. From the values of the focal lengths the corresponding radii

of curvature of the anterior surface as indicated by curve III were calculated.

It will be seen that the curve I does not closely correspond with either the focus or radius curve. Probably the adjustment of the pupil is determined by the amount of the spherical aberration which would result from the passage of the light through the highly curved peripheral zones. Thus the same type of reflex action that controls the ciliary muscles and alters the focus of the crystalline lens when the circles of confusion are too great may also control the sphincter muscle of the iris and by reducing the pupil stop out the portion of the lens that is giving rise to excessive spherical aberration.

(Abstracted from *Translations of the Optical Society*, Vol. XX, pages 209-236, 1919.)

Daylight in the Schoolroom

Edward Jackson, M. D., Miss Katherine D. Blake and John F. Keating

THE eye has evolved to meet the conditions of daylight stimulus, and is capable of its highest health and efficiency under its normal conditions. It is well that the bulk of school work is done by daylight. But of late years an immense amount of thought and labor have been expended on the improvement of artificial illumination, while nothing has been done to improve the methods of using daylight. The result is that artificial light is being used in many respects more intelligently than daylight, and only the innate superiority and cheapness of the latter have left it in general use in schoolrooms.

So little has been done to apply our knowledge of the physiology of vision to the requirements for indoor use of daylight that it is necessary to begin with fundamentals. The light which is useful is that which falls upon the object looked at and is thence sent to the eye, where it enters the

pupil and is focused on the retina. The thing looked at includes both the thing we wish to see and the background which reveals it by contrast, or color difference. We wish to see the letter, but we also look at the paper with which the letter is so contrasted as to reveal its form.

Light entering the eye directly from the source of illumination, or in any way that does not assist in making distinct the thing we wish to see, is not a help but a hindrance to our seeing. For one thing, it causes contraction of the pupil, and in that way actually diminishes the amount of useful light that enters the eye. For another, it wastefully uses up retinal energy accumulated for the purpose of vision, without helping us to see what we want to see. In the third place, it produces retinal impressions that compete with those that are useful for the attention of the recipient, increasing the effort needed to keep the consciousness occupied with the useful impression.

By variation in the size of the pupil which regulates the amount of light entering through it, and by the process of "adaptation" which adjusts the sensitivity of the retina to the intensity of the light reaching it, the eye is capable of service with enormous variations in the brightness of illumination. But there are limits of brightness, beyond which we cannot safely go in either direction. Excessive stimulation unduly exhausts the retina. Deficiency of light lowers the acuteness of vision, and makes more difficult the recognition of objects of a given size and distinctness.

For indoor seeing, the practical problem is largely to get enough light on what we look at. The eye evolved largely for outdoor seeing, and the comparative deficiency of light indoors is enormous. Photography has emphasized this difference. The same film, exposed through the same stop, will require a hundred times longer exposure with a good indoor light than it will require with the light generally available outdoors in the daytime.

The first question to be answered is, How to get enough

daylight into the schoolroom? The second is, How to get it to fall in the right direction? The arrangement to be worked out is one that shall secure the sufficient illumination of the aspects of things that we look at.

It has been customary to say that the room must have enough window space; but window space has little significance, until we know what is to be seen through it, and its position in relation to the student. No amount of window space will give a good light from green foliage; or from a wall, unless the wall is of light color and the sun is shining directly on it.

The test of sufficiency of illumination that can be applied to the plans for any schoolroom is, How much open sky, measured in angular space, can be seen from the darkest point in the room at which objects will be placed to look at? In general this must not be less than the equivalent of a square, each side of which subtends an angle of 20 degrees, for a north light in a cloudy climate. This may be reduced about 50 per cent in a room with south light if heavy clouds rarely diminish the daylight.

Light from Above

Objects looked at are held in front of us, so that light should come from behind rather than from in front. But it has generally been overlooked that the eye is particularly suited to looking down on its work, and to using illumination from above. This is the point in which modern arrangements for artificial lighting have outstripped our plans of admitting daylight to a room.

If one stands or sits with the head erect and the eyes looking forward on a level, the field of vision extends upward about 45 to 50 degrees and downward about 65 to 80 degrees from the horizontal plane passing through the eyes. If without changing the position of the head the eyes are turned up and down, they can turn up about 40 degrees and down fully 60 degrees. If, now, the head is thrown forward

and then backward, it will be found easier to look directly downward than to look 40 degrees above the horizon.

Our eyes are fitted for use looking downward, and all continuous use of them for fine work is done with the work placed below them. The easy position for reading is with the work placed as much below the eyes as in front of them. Very often the position assumed is one looking almost directly down upon the work. Our work is done on desks and tables, with an upper surface horizontal so that it is best lighted from directly above; or inclined, as in the case of some school desks, to an angle of not often more than 10 degrees with the horizon.

We are so constructed that it is more important for the light to come from above than from behind us. That is whence it comes from the open sky: as much from in front as behind, and from both sides; but always from above. We know how unpleasant it is when light is reflected from snow or water and comes nearly as much from below as from above. The great problem in school lighting is to get the light to fall from above. This has been solved for artificial lighting; it remains to be solved for daylight.

The first point is to have the windows go as high as possible. It is often stated that a skylight is the ideal window for illumination, but it is not practical. It can be used only in the highest story, or in one story buildings; it is hot in summer and makes the room hard to heat in winter. These objections to it having been stated, the matter is usually dismissed; and no attempt made to secure the best light possible through windows, the resource that is admittedly practical.

The window should go all the way to the ceiling. The most important reason for having high ceilings is to get high window space. Yet it is common to sacrifice this by placing a foot or so of dead, useless wall, about the top of the window. This foot if utilized to admit light would be worth more than 3 or 4 feet at the bottom of the average window.

There are some mechanical difficulties about having the window begin just at the ceiling, but these are readily overcome. It is possible for the glass of the window to come within 3 inches of the level of the ceiling, instead of from 15 to 18 inches below it, as has generally been the case.

The most popular method, however, of keeping the schoolrooms poorly lighted is the use of an opaque shade, placed at the top of a window. Any shade hung at the top of a window should be white, and of thin, translucent material, which will admit and diffuse all the light possible when the sun is shining directly on it; and it should be rolled up completely when the sun is not shining on it. A dark shade may be placed at the bottom of a window, when somebody has to face it, if the window is so low as to come down near the level of the eyes. Windows in the schoolroom should be made to admit light; this is their primary function, best performed if the bottom of the window is above the level of the eyes. This primary function should not be sacrificed in making the window so that it can be used to look out of. It would be better to make distinct openings for the two purposes. If the window comes just below the level of the eyes, a dark shade can be placed a few inches above the bottom of the window permitting an outlook below it, but pulled up so as to shut off any direct view of the sky from eyes in the usual position for study.

Lighting the Ceiling

The weakest point in the utilizing of daylight for the schoolroom is in the failure to light the ceiling, whence the light could be diffused in the normal direction downward upon the scholar's work. This can be done only by reflection. Occasionally reflectors placed outside the building have been used to illuminate rooms by reflecting the light of the sky obtained through a light-well in the midst of closely crowded buildings.

Schoolrooms should never have such meager access to

daylight. But a highly polished inside shutter placed horizontally can be used to reflect light on the ceiling, and at the same time prevent it from falling on the floor, where it tends to dazzle the eyes directed downward in performing school tasks. Such a shutter should be fastened in place with a hinge that will allow it to be inclined at different angles to meet the differences in the inclinations of the sun's rays at different times in the year. It should extend beyond the sides of the window so as to catch light that would reach the floor when the sun falls obliquely from the right or left of the window. When the light is admitted through a series of windows placed close together, the shutter should be continuous across the whole series. It should generally be about as wide as the distance it is placed below the top of the window, 2 or 3 feet. More than one shutter can be used, placed at different heights before the window, in which case the width should equal the interval between them. Such horizontal shutters will be useful chiefly on windows that receive the direct light from the sun during school hours. But in some cases such a shutter that has a good reflecting surface will materially improve the lighting of the dark parts of the room by reflecting on the ceiling the light of an unobscured north sky.

For buildings so placed that it is impossible to get sufficient clear sky space, to furnish light through a lateral window, a reflecting shutter, placed outside the window so as to reflect light from the sky above upon the ceiling, may be the only practical method of illumination. Such a reflector may be made of milk glass, or frosted or fluted glass. It should be hinged like an inside horizontal shutter, to adjust to different angles; especially if the exposure is one where the direction of strong light will vary at different hours of the day.

Light from any Quarter

Much has been written with regard to having a north

light, of having the light come from one side of the room, and of having it fall over the pupil's left shoulder. Sometimes the south exposure of a school building has been left a blank wall, the opportunity being wasted for flooding a room or series of rooms with the light that was badly needed in them. Cohn declared his preference for a southern exposure. Risley has done the same and has given reasons for his preference.

When the windows are placed high enough and furnished with the proper arrangement of shades or horizontal shutters, the light may be admitted from north, east, south or west, or from all quarters; and is better admitted on two or more sides of the room. Under the inferior arrangements that are still common, it has often been necessary to save the pupils from facing the light by compelling the teacher to face it a large part of the time. In order that right handed children should have the light coming over the left shoulder, the direction favorable for their writing, the left handed children had the shadow of the hand thrown over the pen point, the most unfavorable position for them; and the blackboard and wall charts often had to be placed in unfavorable position, or inconveniently crowded on the only side of the room available for them.

When the windows are placed high enough, they do not shine unpleasantly in the eyes of the pupils or teacher facing that side of the room. The natural arrangement of brow and lashes and the inclination of the head effectively protect the eyes from unpleasant glare. When the light comes in on two or three sides of the room, blackboards and charts may be placed below the windows on sides opposite other windows, and will receive excellent illuminations, while throwing all reflections from their polished surfaces down toward the floor, instead of in the eyes looking at them. One further factor in the lighting of the room is the color and tint of its walls. The predominance of lighting from above is materially increased by having everything above the level of the eyes

in as light a tint as possible, either white or light yellowish or greenish. Below the level of the eyes, walls, floor and seats should be relatively dark, and the surfaces not so highly polished as to give regular reflections that will be annoying.

Instances of Proper Arrangement

When the room can be lighted from only one side, it will always be best to have the length of the room parallel to the wall with the windows in it, and its breadth limited according to the height of the ceiling. Thus, with a 12 foot ceiling, the room should not be more than 18 feet wide. The windows should begin at $6\frac{1}{2}$ or 7 feet from the floor and extend to as near the ceiling as possible, and should take up as nearly the whole length of the one side of the room as is compatible with the strength of the building.

It is assumed that through such windows nothing will be visible except clear sky from every part of the room where anything is placed that has to be looked at. If these windows open to the south, or to the east or west, where the sun is likely to shine in during school hours, they must be furnished with light shades that can be used to intercept and diffuse the direct sunlight, and drawn up entirely out of the way when the sun is not shining on that window. The matter of dark shades, to be drawn up from the bottom is less important if the bottom of the window is as high from the floor as mentioned; it will cause little annoyance, even when entirely unshaded. A room with 15 foot ceiling may be from 20 to 25 feet wide, and the bottom of the windows placed 7 or 8 feet from the floor.

If there are windows on both sides of the room, all having the proper outlook, it may be wider, 30 feet for the 12 foot ceiling or 40 feet for the 15 foot ceiling. Light from one or both ends of the room, through windows of the proper height, cuts out some shadows and gives a more uniformly diffuse illumination, more nearly approaching the ideal of diffuse light from the sky.

Excellent illumination can be secured by extremely simple means, if only the importance of having the light come from above is properly appreciated. In Pueblo, Colo., are two small, one-room school buildings, built on a plan devised by Dr. R. W. Corwin of that city, in which the rooms are as well lighted as any schoolroom we have ever seen. Teacher or pupil may stand in any part of the room and look in any direction without encountering the slightest unpleasant glare, and with adequate light on everything to be looked at. Except the door space, and the small windows placed low, to look out from, every foot of wall space below the main windows is available for blackboards and charts, which are better lighted than is possible for most schoolrooms. The rooms are 29 by 39 feet with 13 foot ceilings. Close to the ceiling, 4 feet of wall space on three sides is utilized for windows, each of which is hung like a transom, so that it can be opened for ventilation. On the two sides where the direct sunlight can fall on the windows a part of the day, the glass is "frosted"; on the north side it is left clear. The frosted glass cuts down the illumination somewhat on cloudy days, and to this extent is inferior to light shades that could be drawn out of the way when the sun is not shining.

Essentials for Illumination

The essentials for good daylight illumination of schoolrooms are few and simple:

1 The selection of a site and plans such that neighboring trees or buildings shall in no case rise more than 15 degrees above the horizontal plane of the bottom of the windows. Large trees, so close to the walls that they can be trimmed up to clear an angle of 60 degrees with the horizon, may be permitted in warm climates where it is important to keep down heat.

2 Placing the windows high enough to permit light from them to fall at an angle of from 15 to 40 degrees in the part of the room most distant from them, shutting off all glare of

light below 15 degrees, and placing such windows on all available sides of the room, and especially to the south, where the most light is obtainable.

3 Controlling direct sunlight by light shades that will intercept and diffuse it, drawn out of the way when not needed for this purpose. Placing all dark shades at the bottom of the level below which glare is excluded from the eyes. Using polished shutters that swing on a horizontal axis to reflect light on the ceiling when obstructions to clear sky render this help necessary.

(Abstracted *verbatim et litteratim* from the *Journal of the American Medical Association.* Vol 76, page 1788, 1921.)

Note on the Relation Between the Frequencies of Complementary Hues

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THERE are available considerable data on the wave-lengths of complementary hues. It appears that such data have always been presented and discussed in terms of wave-length, and not in terms of frequency. It has been suggested that the curves relating complementary wave-lengths "nearly resemble" (rectangular) "hyperbolae." Inspection of Fig. 1 will show that the approximation to a rectangular hyperbola is not at all close; the alleged likeness is rather far-fetched.

It might reasonably be expected that the relation between frequencies would be simpler than that between wave-lengths. From the point of view of physiologic optics, wave-length can be nothing more than a purely arbitrary reference scale; while it is at least a reasonable hypothesis that some comparatively simple relations may exist between the retinal response and the frequency of the stimulus. The author has previously shown that retinal visibility as a function of frequency is simpler than as a function of

wave-length. In this paper it is proposed to show that the relation between the frequencies of complementary hues can be represented in a simple way which is at least suggestive of simple relations between the retinal response and frequency.

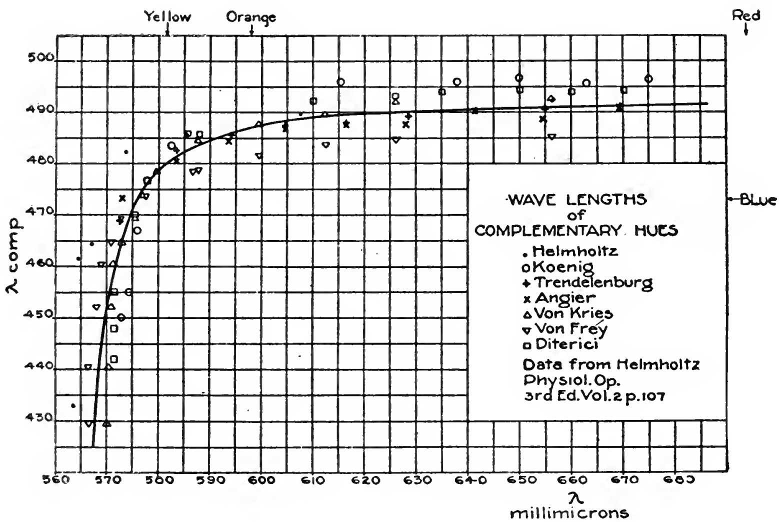

Fig. 1

The data mentioned above have been replotted, as shown in Fig. 1. A curve has been drawn to represent, as well as may be, these data. From this curve pairs of complementary wave-lengths have been read. These wave-lengths have been converted into frequencies; and the relation of frequencies has been plotted (solid curve Fig. 2). The circles in Fig. 2 have been plotted from the equation of a rectangular hyperbola:

$$(530-f)\,(f_{comp}-608)=220$$

That is: The relation between the frequencies of comple-

mentary hues can be represented closely by a rectangular hyperbola of which the asymptotes are:

530 and 608

and the focus is:

509.2, 628.8

There is at present considerable interest in another re-

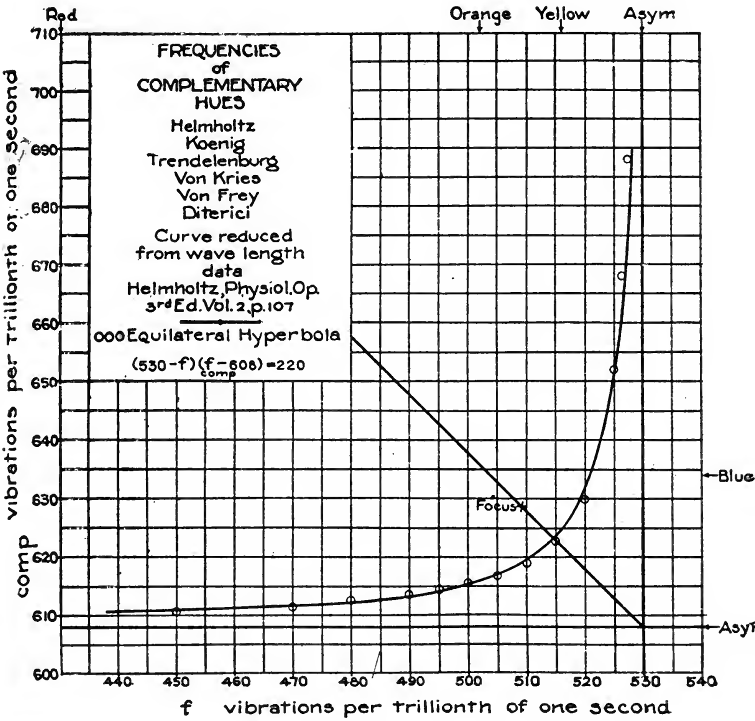

Fig. 2

determination of the visibility function. In order that such a determination might yield the largest results, the author would suggest that visibility should be represented as a

function of frequency and the visibility of each subject should be correlated with:

1 The frequencies of his spectral complementaries.

2 His hue sensibility to frequency differences as a function of frequency.

3 The "black-body" spectral energy distribution which he recognizes as gray.

4 The relative intensities of homogeneous complementaries required to be mixed to color match gray specified by the findings under (3) above.

By the correlation of these functions we might reasonably expect to gain a new insight into the various phenomena of color and perhaps elucidate somewhat the nature of the retinal response and its relation to the stimulus.

(Abstracted *verbatim et litteratim* from the *Journal of the Optical Society of America*, Vol. IV, p. 402–404, 1920.)

920

321

The American Journal *of* Physiological Optics

The Revelation of Disorders of the Apparatus of Binocular Vision

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THE dawn of the discovery that the motor apparatus of the eyes might have some relation to the many troubles of the organ of vision which so baffle the refractionist, and that this delicate and complicated apparatus may be the seat of so many groups of nervous disorders, does not date far back into the last half century.

The tenacity of the faith the oculist has had in the last fifty years in Professor Donders' system of *Refraction and Accommodation* to relieve all symptoms of asthenopia, may be an evidence of its great worth to ophthalmology, which we all acknowledge. But it is now challenged for its want of infallibility in the light of the broader and more comprehensive study of the many and various symptoms that have been found to be caused by eye disorders.

The earlier discoveries made in defects of the eye, which were embodied in Donders' system, were made by non-medical men—physicists, of whom Donders himself was one, as well as Thomas Young, Airy, Helmholtz. It was a mechanical contribution to the profession of ophthalmology and ocular refraction.

The question why, with all the clinical evidence of physiological analogy pressing for attention upon the responsible specialists, a course of investigation closely belonging to

the paraphernalia of the engineer, and that only, should be applied, ought to be submitted to a court of psychology.

Dr. Dyer in 1865 and Dr. Noyes in the '70's had a suspicion of the physiological condition of asthenopia. Drs. Stevens and Savage in the '80's undertook to repair the motor apparatus mechanically. But it is due to Dr. Wier Mitchell of Philadelphia, a nerve specialist, to attribute many nervous diseases to eyestrain, and send them to those who took care of such defects.

There is now a consensus of opinion that the symptoms, so often found in connection with eyestrain, are reflex in their character, and are not pathologic, for when the cause in the eyestrain is reached, the symptoms are removed, like taking off the hat, and the patient set free.

It is due to von Graefe to recognize weakness of the converging muscles, which he called "insufficiency." This was a sign on the road directing a cause that has been recognized. Why is it not more fully accepted that other muscles of the eyes are weak?

The fact stands out emphatically, that we who administer to eyestrain must change our viewpoint in regard to this apparatus and consider its significance as being the moving power of the *function of binocular single vision, called ocular orientation*, and care for it as such. It is the seat of more than half of asthenopic troubles. From my experience of twenty-five years in handling these muscles on this theory, there follow much better results in curing eyestrain. This is the care of the organs of vision on the *physiological* aspect of the problem of eyestrain.

It seems extraordinary that in this day it is necessary to describe this function called ocular orientation, presided over by this apparatus, which plays such a conspicuous part in securing safety, and success in most of our avocations, and the seat of two-thirds of the symptoms of asthenopia. Yet it is a fact that this function is not recognized as an entity in visual science; it is not the subject

of test as a whole, and several of its elements of good action are not thought of in the examination of this sense.

It is the office of this function, by its delicate mechanism of the muscular apparatus, to maintain single vision by the fusion faculty in whatever portion of the horopter (that is the section of the field in which it is projected) this may be involved. The changes of point of vision from one place to another, under some circumstances, and in the short space of time it is accomplished, seems almost incredible, yet in the normal condition it is perfect in adjustment, and, working in harmony with the focusing, is so quickly done that no confusion is experienced, and perhaps no thought is directed to the organs that have piloted the subject and furnished the brain with facts on which are based judgment of distance, relation of objects, of depth, thickness, as well as speed of movements that adjusted the eyes to so measure. These muscles are the quickest in the body and man is the only animal that has developed this function to this perfection.

Safety of the person and the ability to perambulate without accident depends on its accuracy; success in manipulation and facility in handiwork and indeed in every occupation, from digging a ditch to participating in a tournament, rests upon this faculty and exactness of this mechanism. Freedom of motion, vivacity of spirits, love of observation demand its best exercise. Judgment of form, contour, and appreciation of animal grace, symmetry and proportion cannot be had without its perfect work. Healthfulness, love of life, desire of seeing, craving for out-of-door sports, walks, love of rides and travel depends largely on the perfection of this wonderful function of binocular single vision.

It seems very logical to the mind of one who has adopted the orthoptic method of dealing with these recalcitrant muscles, that, to overcome too strong innervation of the internal recti, is to diminish accommodation by convex

glasses as Donders taught, and if need be to get paresis of the accommodation, and then discipline the antagonistic external recti and, contrarywise, in cases of weakness of the internal recti to increase their innervation to do their duty.

The conception of discipline of the ocular muscles in the '60's was very crude. The training of the muscles of the body has been carried on for centuries. But a like attitude of the gymnast towards the ocular muscles will not do. These muscles are not built for strength but for speed, "their fibres end to end," and they require different handling; there is obstruction to be gotten rid of; the art of muscular training of these muscles has been very slowly developed and very little understood.

The idea that the cause of trouble in asthenopia may be in the extrinsic muscles as well as in the refraction being fully aroused, there arose much interest between the two factions. Now the theory of imbalance of these muscles and the correction by tenotomy has had its full test and is now waning.

The writer fully believes that the problem of eyestrain is in the disorders of the *function of the binocular apparatus of orientation;* that the full operation of its machinery is interfered with or obstructed; that refraction is but a secondary matter, but is included in the conception.

The problem of motoring and aviation, primarily, is in the engine; it depends upon the reliability of the function of movement. This is forgotten in this prominent function of the human body, and here not only must the engine problem be solved in motoring the earth and sky, but the pilot himself must have good orientation withal.

It is not necessary to depict the various conditions that are found under the name of eyestrain. The literature of ophthalmology is loaded down with them; some cases reported as being made comfortable by glasses, but at the expense of inattention paid to the weak function of orien-

tation, and volumes of biological reports of people who were never relieved because they had not the service of an American specialist. Many severe cases were those who, living in America, were glassed, and were said to have been relieved, but one understanding it can see it to be at the expense of *assisting one eye to swing out to a useless position* and destroying the function of binocular vision—a hideous spectacle of inefficiency and want of thoroughness of service.

I have already written extensively upon my theory of etiology of the disorders of these muscles. Two articles in the *Archives of Ophthalmology*, New York, 1920, Vol. XIIX, Nos. 1 and 4; also one in the *American Journal of Physiological Optics*, Vol. 2, No. 1 (January 1921) and in a book, *New Findings in Ophthalmology and Otology*, 1911.

From experience in examination and treatment of this function, I have come to the belief that half of the general run of people have a want of proper functioning of this apparatus. There may be no pain or discomfort, but there is a disability of functioning which discounts their efficiency in handiwork, and prevents them from participating in the many activities of every-day life and from fulfilling their possibilities—other things being equal.

In the normal condition of this function one is able to overcome a prism of 25^{Δ}, base out, put over one eye when, for instance, the projection is made upon the moon in a clear atmosphere,—that is, fuse the two objects produced by it—instantaneously. The act of fusing is sometimes done so quickly that the two moons are not observed. I often find those who cannot correct a 5^{Δ} prism thus held. The standard of correction is 50^{Δ} for these muscles. In the other pairs of muscles of the system, the excursion of the ball is not as great and the fusion act is less. Now when a person is slow in correcting a 10^{Δ} prism by the laterals, there is disability of the function.

This procedure of throwing the image of the moon onto

the periphery of the retina is like the approach of an object to the side and calls on the function of orientation to locate and measure its relativity. If the muscles are normal *in obeying the fusion sense*, there will be a uniting of the objects. In some activities there are hundreds of such requirements in a minute.

I am led to believe that a high percentage of people do not properly perform this act, and when it comes to a succession of the necessity of fusion the object is doubled and confusion arises and to get rid of it they have acquired suppression of the vision of one eye, and then they are in the dilemma of a one-eyed person.

When, even, asthenopic symptoms are not produced, there is awkwardness, slowness of motion, want of observation, imperfect comprehension, a dread of motion.

That the refractionist may be the sharpener of the wits of his fellow men is not an impossible conjecture.

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Malingering—Pretended Blindness

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MALINGERING is one of the most important and most difficult problems the refractionist of modern times has to meet. Very little has been written on this subject and not much of it is taught in schools or colleges giving instruction in refraction and as a result most practitioners are at a loss when confronted with a case which may involve malingering.

The malingerer is not to be found very often amongst the ordinary run of the refractionist's patients. When a person is malingering he or she has a motive behind it. He is trying to collect damages as a result of a supposed or real injury. In this modern day of the automobile and its many accidents, of life insurance with its total and partial permanent disability clauses and of sick and accident insurances, as well as workingmen's compensation laws, we are bound to find individuals who are trying to obtain compensations or insurance on the least pretext. Sometimes these persons claim greater defect or loss of eyesight than really exists in order to secure greater judgments for the injury of the eyes. Others pretend blindness in order to secure pensions, some to avoid military service and some in order to be admitted to some charitable institution. Sometimes children pretend blindness in order to be relieved from school duties.

The refractionist of today should familiarize himself with the different methods for the examination of malingerers in order that, when called upon by the court or insurance company to examine a claimant, he may be able to determine whether the claimant actually has some eye defects and impaired vision, or is simply malingering and to what degree.

Malingering may be divided into three classes:

1 Total blindness in one eye.
2 Partial blindness in one eye.
3 Total or partial blindness in both eyes.

I. TOTAL BLINDNESS IN ONE EYE

Total blindness in one eye is usually claimed by many who try to evade the military service, or those who try to collect partial permanent disability on their accident or life insurance policies or by those who become injured while employed at a place where workingmen's compensation insurance is carried. To find out whether total blindness exists, many tests may be performed which will help the examiner very much. These tests may be divided into two classes:
1 Objective
2 Subjective

Objective Tests

Objective tests are: (a) Pupil reaction; (b) Vision fixation test; (c) Objective prism test; (d) Static retinoscopy; (e) Dynamic retinoscopy; (f) Objective monocular accommodation; (g) Ophthalmoscopic examination.

Pupil Reaction. If the pupil of the eye which is exposed to light contracts there is a probability of sight in that eye. To test the pupil reaction the subject under examination is directed to look forward. The examiner covers both eyes with his hands, thereby cutting the light off from the subject's eyes. The hands are quickly removed and the reaction noticed. If the pupil reacts to light there is evidence of some sight and the better the reaction the more vision there is. The degree of sight cannot be measured by this test. There is, however, a positive value to this test. That is to say, if there is no contraction of the pupil to which the light is applied and there is a reaction of the pupil of that eye to which the light was not applied (*i. e.*, consensual reaction takes place) there is evidence then that the eye is blind.

As the pupil also reacts under accommodation and convergence, it is, therefore, essential in making this test to have the subject look at a fixed distance during the period of the examination.

Vision Fixation Test. When an eye is partially or totally blind it fails to maintain proper fixation. If when, under all conditions, perfect parallelism exists, there is good proof that there is some sight present. The sight may not be as good as in the other eye, but at least it is good enough to produce and maintain binocular single vision. In this test the examiner should be on his guard for cases of persons who may consciously or unconsciously disassociate accommodation from convergence and in that way suppress the image of one eye. These cases are usually strabismic and are easily detected.

Objective Prism Test. A prism, 10 degrees, base out, is placed before either eye. In binocular vision the cornea of the eye before which the prism is placed is rotated inwardly, unconsciously and involuntarily, as the false image is fused with the true image.

Static Retinoscopy. It is needless to describe in detail how to perform this test as every modern refractionist knows retinoscopy and how to use it. If the error of refraction is small there is no cause for blindness, or materially reduced vision, in so far as accommodative and refractive conditions are concerned.

Dynamic Retinoscopy. This test should be made with fixation and observation at 13 inches. If under this test the error is also low and varies but little from the static retinoscopic measurement, the claim of blindness may be considered merely as pretended.

Objective Monocular Test. This test is made by placing the correction in front of patient's eyes. Cover one eye and examine the other. The examination is performed in the following manner: Have the patient look at an object like a pencil or finger at a distance of 13 inches. The object is to be held to the nasal side of the eye during the ex-

amination, while the retinoscopic examination is made from the temporal side as close to the visual line as possible. The test object is moved as near to the eye of the subject under observation as will still permit of its being seen. The observer with the retinoscope moves forward till he obtains a neutral shadow position. This distance is carefully measured. The same procedure is carried on in examining the other eye.

The distances obtained from the examination of each eye are compared. If there is but little difference in the distance of the neutral point there is also little difference in the accommodation of the two eyes. The subject should be able to see as well with one eye as with the other.

This test is very simple and interesting. For more detailed explanation about this test and the theory involved, we make reference to Sheard's *Dynamic Skiametry*.

A case which will best illustrate this test is that of Mr. H., aged 24. Static retinoscopy, O. D. +1.00 D.S., O. S. +5.50 D. S. Dynamic retinoscopy, O. D. +1.75 D. S., O. S. +6.50 D. S. Subjective static tests, O. D. +1.00 D. S. V=20/20 O. S. +4.50 D. S. V=20/200— and could not be improved. The objective monocular accommodative test showed O. D. had 6 D. of accommodation, but the near point for the left eye was less than 20 inches with no improvement. In a case like this we can be satisfied that the left eye has very little visual acuity.

Ophthalmoscopic Examination. This examination is very essential, for blindness in some cases may prevail, even if there is only a low error of refraction found, as long as there is found a fundus lesion, some pathologic condition of the choroid, retina or cloudy media.

Subjective Tests

Subjective tests are: (a) Binocular reading test; (b) Duane's method; (c) Prism base up and down test; (d) Double prism test; (e) Pin hole test; (f) Ten diopter convex lens test; (g) Test with Worth amblyoscope.

Binocular Bar Reading Test. While the patient is reading small type on reading card at near, a pencil is held in front of the card by the examiner. The ability to read uninterruptedly proves that both eyes are functioning, as the pencil cuts off the letters and words from each eye on different places on the card and could not be read monocularly without interruption.

Duane's Method. Have the patient read aloud and quite rapidly. While occupied with what he is doing, quickly place a four degree prism base down in the front of the alleged blind eye. The examiner should be certain that the eye is open at that time. If the eye is totally blind or vision is very poor, the placing of the prism will make very little difference in the reading. He will be able to read just as well as before the prism was placed in front of the eye. But if there is some sight in that eye he will not be able to read or will at least stumble, as the placing of the prism will produce double vision.

Test with a Pair of Five Degree Prisms. Place one prism base up and the other base down in front of the subject's eyes. Have the patient hold a card about four by six inches with a horizontal line of large print (12 to 14 points). Ask patient if he sees four rows of print or only three. If he claims he sees two only there is good proof that there is vision in the alleged blind eye.

Double Prism Test. Place a double prism in front of the good eye, and an opaque disk in front of the other eye. Have the subject hold a card with a horizontal line of print on it. Ask the subject whether he sees one or two lines. If he claims he sees only one line there is proof of dishonesty. For the double prism in front of the good eye produces double vision, hence, he must see two lines with the good eye. Care must, however, be taken that the prism is properly placed in front of the eye.

Pin Hole Test. Place a pin hole disc in front of the good eye so that the small hole is as near the center of the pupil

as possible. Have the subject read at distance or at near. His head is then to be slightly tilted downward till the visual line comes above the pin hole. If the subject is still able to read he is doing it with the alleged blind eye.

Test with a 10 D. Convex Lens. Place a 10 D. convex lens in front of the good eye. This eye becomes artificially myopic and will have its focus at four inches. Hold a reading card with fine sized print on it in front and very close to the patient's eye. As he reads, gradually remove the card farther away till it is outside of the focus of the lens. If he is still able to read he is doing the same with the alleged blind eye.

II. PARTIAL BLINDNESS IN ONE EYE

In partial blindness the test may be made objectively or subjectively. The objective tests have already been described under total blindness. Some subjective tests only will be mentioned here.

Subjective tests are: (a) Jackson's convex and concave cylinder test; (b) Snellen color test; (c) Mirror test; (d) Movable chart; (e) Kurtz's visual acuity test.

Jackson's Convex and Concave Cylinder Test. Place a +6.00 D. C. and a —6.00 D. C. axis parallel in front of the good eye so that one lens neutralizes the other. Have patient read on distance test chart and turn front cylinder slowly till the axis of one cylinder is perpendicular to that of the other cylinder. If the patient is still able to read he is doing so with the poor eye.

Snellen Color Test. This test is performed by using a chart made up of a series of transparent Snellen letters, alternately, *red* and *green*, in a frame. A red lens of such a shade as to entirely quench the green letters and a green lens of such a shade as to entirely quench the red letters is placed in the trial frame. The chart of the transparent letters is to be hung on a window with plenty of illumination. Then, for instance, if the patient claims his left eye to be the poor

eye and the red lens is placed in front of the right eye he should be able to read the red letters only and the green letters will appear to him black and not distinguishable. If, however, he can also read the green letters he sees those with the alleged poor eye. The acuity of vision can be measured by the size of letters he reads on that chart.

The principle of this test lies in the fact that while rays of a similar color may pass through a colored glass, rays of a complimentary color are stopped. This test is very valuable and easily and quickly performed, but care must be taken that colored lenses are of such a shade as to completely quench the complimentary colors of the transparent letters.

Special Test Card. Instead of commencing with the single top line of 20/200 letter, the test chart should commence with the 20/70 or 20/50 letter. Many recruits and claimants for disability or accident insurance who have some defect or injury in one eye try to exaggerate and are fully determined to read only the first letter on the chart. This chart then eliminates this class of exaggerators, as nearly all of them read the first letter without difficulty, which is, as the case may be, 20/70 or 20/50.

Mirror Test. A mirror is placed on the wall along side of the test chart. A similar chart with letters reversed is placed above the head of the patient. He reads a certain line on the regular chart and then is directed to read the same line in the mirror. By so doing his vision is shown to be twice the amount that the subject claims it to be.

Movable Chart. The purpose of this is to expose only one line of letters at one time. This eliminates the chance for comparison, as the claimant can see only one line at a time and cannot exactly judge what size of letters he is reading.

Kurtz's Visual Acuity Test. This test is performed by using a set of white wooden cubes and a set of white wooden balls, made up exactly of the same size as the letters on the test chart (*i. e.* there is one cube and one ball in the set for every line of letters there is on the test chart from 20/200

to 20/20 inclusive). One ball and one cube are placed at 20 feet distance on a black background 12 inches apart. The subject is asked: Which is the ball and which is the cube? The smallest set in which he can distinguish the difference between the ball and cube measures his vision.

It is not sufficient that he sees where the objects are located, for this would simply indicate that he has the perception of a white object at a certain distance, but he must be able to distinguish between the ball and the cube. In this way the acuity of vision is measured the same as by reading the letters of the same size on the test chart.

This test has proved itself to be of great value where others have failed. No matter how the claimant may be coached on the test chart he cannot outwit the examiner, as he has no means of comparing the size of the test objects with any line of test letters. An illustrative case may best explain how this test is employed.

Recruit L., age 24, white. On the record from previous examinations he had O. D. 20/200 O. S., 20/100. Refractive error was very small. He claimed at the examination that lenses did not in the least improve his vision. Fundus was normal and media clear. There was no cause for poor vision but we did not have the proof that he could see better than he claimed. We then used the Kurtz visual acuity test and by interchanging and mixing up the cubes and balls it was found that the recruit could tell the difference between the 20/30 ball and cube. This was established as being correct by a number of trials. We then placed a +0.12 D. S. in front of his eyes and told him that with these glasses his eyes had been made perfectly normal and that he must be able to read on the test chart the 20/30 line. Failing to do so would mean that he would have to suffer the penalty for malingering. He responded quickly and read the 20/30 line on the test chart without missing even one letter.

The placing of a low power spherical lens in front of

recruits' eyes is merely psychological and has a double purpose. First, by telling him that with this lens his eye is made perfectly normal and he *must* be able to read a certain line on the test chart, he is indirectly told that the examiner knows the exact condition of his eyes and he would therefore be afraid to continue stalling. Second, it is much easier for a subject with a lens in front of his eye to read a certain line on the test chart, which he previously under no circumstances could read with his naked eye. He feels that he is now reading something he claimed he could not see before, but he is doing it under different conditions, for he is doing it with a supposed lens correction in front of his eye.

This test is also valuable for illiterates and young children. No hard and fast rule can be laid down as to which test to use in each case. It all depends on the subject and the examiner. The necessity of the examiner being on the alert cannot be over-emphasized. An alert examiner with all these tests at his command will not have any difficulty in discovering a malingerer no matter how well trained he may be in the art of deception.

Another interesting case may be cited. A recruit, upon examination, claimed to be entirely blind in the right eye since birth. There were two captains and one lieutenant in charge of the eye examining department at that time. They were all convinced that the recruit was stalling but they could not prove that to their own satisfaction. The writer happened to come in to the examining room at that time and they turned the case over to him and asked him to try and prove whether or not the man was malingering. After making a few tests which were not successful we succeeded finally by using a weak convex lens in front of the left eye and an opaque disc in the front of the right eye and making the patient believe that the left eye was the one that was covered. He was then told to walk across the room. This he claimed he could not do, as he could not see

the light with the right eye. This of course proved that he was malingering, because it was his right eye that was covered up with the opaque disc and the left—the seeing eye—was uncovered. The manipulation and changing of the lenses and disc had to be done quickly in order to get the subject so confused that he could not tell which eye he was using.

Test with the Worth Amblyoscope. This test has been used at times with great effect. Especially is this test very useful when you have to prove to a jury that the claimant is malingering. From the tests already mentioned the examiner can find out for himself whether the claimant is malingering or not. These tests are more or less technical. By properly using the Worth amblyoscope the examiner is able to not only detect malingerers for himself but can also prove it to others. To make this test the amblyoscope should be so arranged that the images are crossed when looking through it with normal eyes. The amblyoscope should be placed on the table in such a manner that the patient shall see clearly that the tubes do not cross. Now let us take two objects; say a bird and an arrow. The bird will be placed in the tube which will be seen by the right eye (the blind eye) and the arrow which is larger than the bird be placed in the tube seen by the left eye (the seeing) eye. It should be remembered that the amblyoscope is so arranged as to have the images crossed, so that the arrow will be on the right though seen by the left eye and the bird on the left though seen by the right eye. If the claimant is malingering he will claim to see only that object on the side of the seeing eye, in this case the bird, which in reality is seen with the eye claimed to be blind. This is conclusive proof that the claimant not only is malingering, but also has good sight in the right eye.

III. TOTAL AND PARTIAL BLINDNESS IN BOTH EYES

Simulated total blindness in both eyes is unusual because it is difficult to carry out. This may sometimes be pretended by persons who have amblyopia in both eyes or by hysterical persons.

A really totally blind person has definite and peculiar characteristics. He has a dull stare, eyes are turned upward and slightly outward, has an expressionless face and walks hesitatingly. The objective tests are the same as for any other form of malingering. There are a few subjective tests for these cases.

The examiner may pretend that he is testing the sense of direction. The examiner may go to one end of the room and ask the patient to approach him. A piece of furniture may be placed in his way and the examiner should observe whether or not the patient is trying to avoid the objects placed in his way. Care, however, must be taken that the patient should not get injured.

Schmidt-Rimpler suggests that the patient be told to look at his own hands which he holds a short distance from his eyes. If he looks in a different direction he is only a pretender and believes that he is this way deceiving the examiner. A blind person can easily succeed in casting his eyes in the direction of his hands.

Priestly-Smith suggests the application of the Van Waltz test. The patient is placed in a semi-darkened room, a candle light is to be placed in front of him so that he will naturally cast his eyes in the direction of the candle without being instructed to do so. A prism, base in, is placed in front of one eye. If vision exists the eye will move outward and again inward when the prism is removed.

It is not necessary to perform all the tests mentioned in order to examine a malingerer. The examiner will find that with some of these tests it will be very difficult for the most expert malingerer to deceive him, and in some cases it will take a great deal of cleverness, alertness and knowledge on the part of the examiner to outwit the malingerer who may be well informed and trained in the art of deception.

Minneapolis, Minnesota

The Effective Power of an Ophthalmic Lens

Charles Sheard, Ph. D.

AS ophthalmic science has advanced, the necessity for more accurate units and methods of measurement of the powers of spectacle lenses has kept pace. In bygone days, when spectacles were called for and sold over the counter by "numbers," when the art and science of refraction were in their development stages and when quarter and half diopters of either spherical or cylindrical corrections were neglected, it was obviously of little significance to those who tended to the needs of the spectacle wearing public whether or not the exact lens power needed by a pair of eyes was obtainable or not. But the past fifty years have evidenced marked achievements in the field of physiological optics, so that today, as we near the close of the first quarter of the twentieth century, we find practitioners taking into account in their refraction every little factor which will contribute to accuracy and exactness in their findings. And to a considerable degree, we find that the spectacle wearing public is coming to a realization of the fact that the efficiency, comfort and usability of a pair of eyes is enhanced by this progress made in ophthalmic and optical science.

Neutralization

Up to within a comparatively few years the neutralizing method was the only means available for the determination of the accuracy of finished lenses supplied to the wearer. When only biconvex and biconcave forms of spherical spectacle lenses were known to the ophthalmic world, this system served very well when weak powers of lenses were used. In 1899 Charles F. Prentice discussed the problem as to why strong contra-generic lenses of equal power failed to neutralize each other. Due to his investigations, there-

fore, concave lenses—which can be made *thin* lenses at the central portion—were taken as the standards and the biconvex lens curves were so modified as to neutralize these thin biconcaves. That biconvex and biconcave lenses of the same curvatures cannot neutralize is evident from a consideration of Figure 1. For if we extend the outside and inside curves of the two lenses shown in Figure 1 we

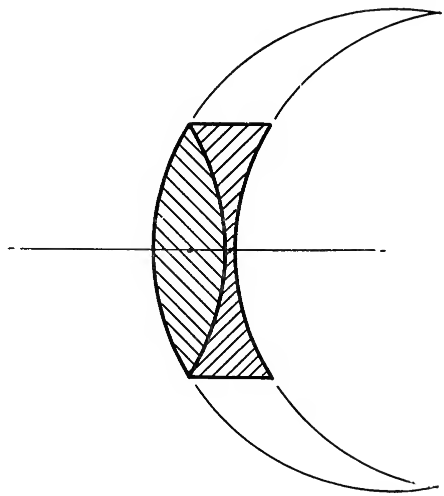

Fig. 1. Biconvex and biconcave lenses of the same curvatures cannot neutralize.

find that the combination forms a single lens of a meniscus shape which is essentially plus in value.

With the advent of meniscus and toric lenses the whole matter of the determination of the true power of a spectacle lens became more intricate. Figure 2 illustrates the fact that if a meniscus lens were to be neutralized from the ocular side of the lens (meniscus or toric), three lenses would be involved. No. I is the meniscus lens, No. II is an air lens with glass as boundary surfaces, and No. III is the

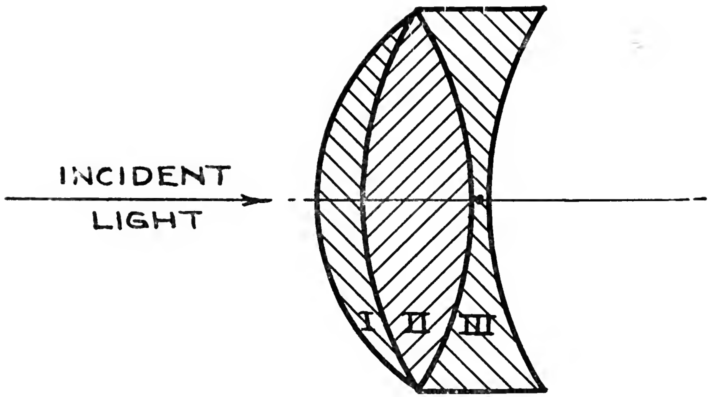

Fig. 2. Neutralization from the ocular side of a lens means that three lenses will be involved.

neutralizer which has, presumably, determined the power of No. I.

In practice, therefore, the neutralization of ophthalmic lenses is accomplished by holding the lens to be neutralized in contact with the neutralizing lens as shown in Figure 3. In this case the light is *incident* upon the lens to be neutralized at its ocular surface, *i. e.*, the side from which the

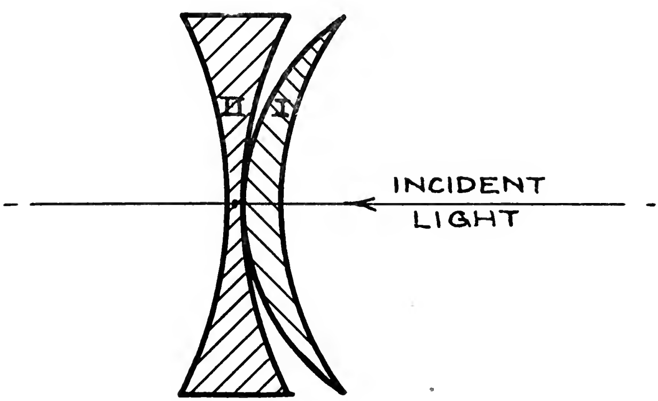

Fig. 3. Neutralization from the front surface, which means that the front instead of the back focal length is determined.

light, when the lens is before the eye, is *emergent*. Hence neutralizing power, under such conditions, would be a measure of the power of a lens if worn in a position the exact reverse of that in which it is worn. But mathematical and experimental optics show that the power of a meniscus or other so called periscopic form of lens is not the same when measured from the ocular surface as when measured from the second surface.

Thin and Thick Lenses

If all ophthalmic lenses were of biconvex or biconcave form or were infinitely thin, then neutralization methods would be sufficient. *Shape* and *thickness* of lens are, therefore, two very important factors affecting the determination of the power of a lens. The matter of curvatures we have briefly discussed: we shall now consider the effect of thickness.

The *approximate* power of a lens may be obtained by adding the power, D_1, of the front surface to the power, D_2 of the second or rear surface. Then $D_1 + D_2$ is a fair approximation of the power of a thin lens. That is, a lens may be considered thin, or as having no appreciable thickness relative to the value of the focal length, if the refraction caused by the two surfaces may be presumed to take place at a single refracting plane which the two surfaces touch passing through the *optical center*. A thick lens differs from a thin one in that it has, in addition to the surface refraction, an internal plate of glass which has the power of laterally displacing incident light. This is illustrated in Fig. 4 which shows in I a thick lens with certain curvatures and in II a thin lens with the same curvatures.

And again, the position of the optical center varies with the form of the lens and must be mathematically determined for every set of curvatures used, except for biconvex and biconcave lenses, in which the optical center is known to be the middle point of the lens, this point lying on the principal optical axis.

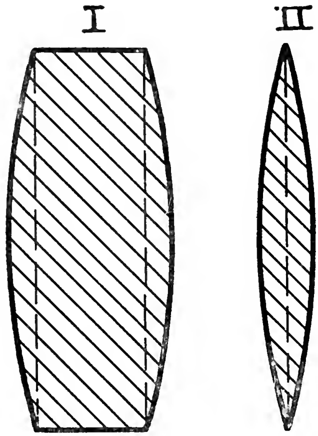

Fig. 4. Thick and thin lenses.

Fig. 5 shows the optical center (O) of a thick biconvex lens as well as its principal planes and principal or nodal points (N_1 and N_2).

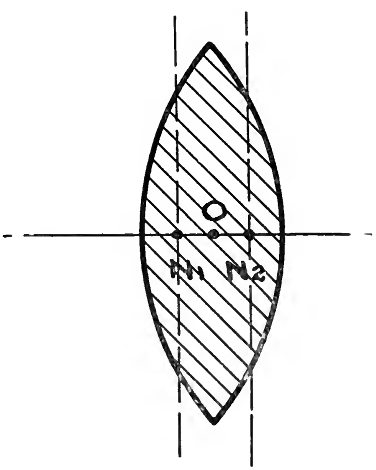

Fig. 5. Showing the optical center, principal planes and principal points of a biconvex lens.

Fig. 6 gives the graphical representation for a meniscus form of thick lens.

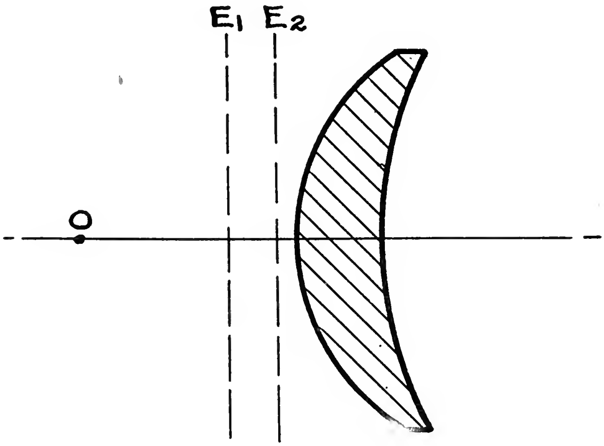

Fig. 6. Showing the optical center and principal planes of a meniscus form of lens.

It is therefore apparent that the power of a thick lens could not be determined by a measurement of the focal length with either the optical center or either of the nodal points as a starting point, for these points are variable in position.

We have, therefore, up to this point called attention to the inherent difficulties in neutralization and made the statement that optical centers and nodal points of a lens cannot be used in common practice as the point from which to measure focal lengths and hence determine powers.

Effective Power

One obviously easy and practical, as well as theoretically ideal method of determining the power of a lens lies in the measurement of its focal length from a point on the optical axis and which, in addition, lies upon the ocular surface.

In Fig. 7, therefore, the *back focal length* of the lens would be designated as the measurement of the distance A F, in which A is a point upon the ocular surface and F is the focal point. Hence the *effective focal length* of this lens, whatever its shape and thickness, is its back focal length, A F.

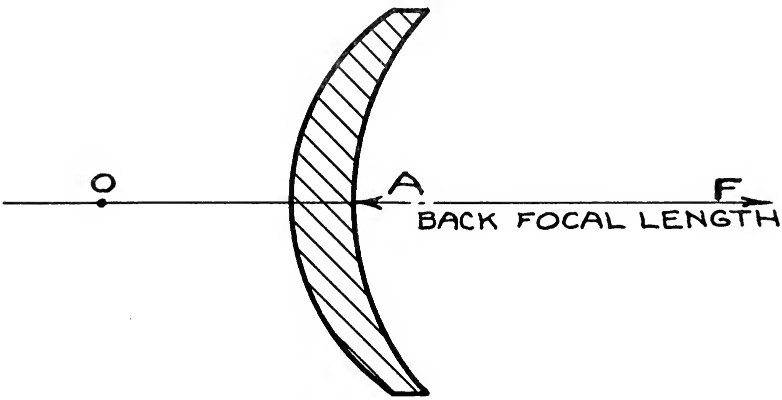

Fig. 7. Back focal length, or effective focal length.

Spectacle lenses may be worn at different distances before the eye and are modified in their correcting effect by the distances they are away from the cornea. In ophthalmic optics, we must therefore take a fixed distance of the lens from the cornea before we can truly define effective power. Obviously the ocular surface of the lens cannot be put in contact with the cornea. Therefore, a point 14 mm. in front of the cornea has been universally chosen as the recommended distance, although not absolutely essential. This point has been chosen because it lies in the plane of *unit magnification*. This means that any lens, when worn in this position, does not either magnify or minify the size of the retinal image. But, in any event, the distance of the

wearer's lens must be the same as that of the ocular surface of the trial lens at the time of the eye examination. This is an important factor.

By *effective power* or *vertex refraction* we mean the power which is determined as the reciprocal of the distance from the ocular surface to the ocular focal point.

Such a unit of power, therefore, is universally applicable to any shape or thickness of lens, as well as any combination of lens, whatever the index of the glass used may be.

Simple Formulae for Effective Power

There are two simple formulae which enable the approximate effective power and neutralizing power of any lens to be arithmetically calculated:

Approximate *Effective* Power $= D_1 + D_2 + t/n\ D_1^{\,2} + \ldots\ldots$
Approx. *Neutralizing* Power $= D_1 + D_2 + t/n\ D_2^{\,2} + \ldots\ldots$

in which

D_1 = power of front surface in diopters
D_2 = power of rear (ocular) surface in diopters
t = thickness of lens in meters
n = index of refraction

Suppose we have three lenses, the sum of the powers of the two surfaces being +16D. Lens No. 1 is biconvex, lens No. 2 is convexo-plane and lens No. 3 is a meniscus with a —6D. curve on the ocular surface. All lenses are of the same thickness, namely: 6.4 mm., and index of 1.50. The *effective power* of lens 1 is +16.28D; lens 2, +17.18 D; lens 3, +18.28D. The *neutralizing* power of lens 1 is +16.28D.; lens 2, +16D.; and lens 3, +16.17D.

For the sake of illustration we give below the arithmetic of the solution of finding the *approximate effective* and *neutralizing* powers of a lens having a power D_1 of + 22D. on the front surface, a power D_2 of — 6D. on the ocular

surface and a thickness of 6.4 mm.; the index being 1.50.

$$\text{Approximate } \textit{Effective} \text{ Power} = 22 - 6 + \frac{.0064 \times 484}{1.5}$$

$$= 16 + \frac{3.097}{1.5}$$

$$= 18.07\text{D.}$$

$$\text{Approximate } \textit{Neutralizing} \text{ Power} = 22 - 6 + \frac{.0064 \times 36}{1.5}$$

$$= 16 + 0.16$$

$$= 16.16\text{D.}$$

It should be noted that the terms beyond the third term in the equations given are of greater significance in the higher powers of lenses than they are in low powers and must be included in getting the *true* effective power. In the particular case which we have taken, the fourth term of the equation amounts to +0.21D.; therefore this amount should be added to the sum of the three terms already calculated in order to obtain the *true* effective power. This gives a total of 18.07D. + 0.21D. or 18.28D.

If we take a lower powered lens, such as a + 3D.S., and assume a thickness of 3mm. we find the *approximate effective* and *neutralizing* powers for a lens having a —9D. curve on the ocular surface and a front surface of + 12D. power to be given as follows:

$$\text{Approximate } \textit{Effective} \text{ Power} = 12 - 9 + \frac{.003}{1.5} \times 144$$

$$= 3 + 0.29$$

$$= 3.29 \text{ D.S.}$$

$$\text{Approximate } \textit{Neutralizing} \text{ Power} = 12 - 9 + \frac{.003}{1.5} \times 81$$

$$= 3.16 \text{ D.S.}$$

These calculations show conclusively that the shape (surface curves) of a lens and its thickness have important effects upon both its effective and neutralizing powers.

Hence, the important property of a lens is its corrective effect upon the eye and this depends not only upon the curves of the two surfaces, but also upon the thickness, shape and position of the lens before the eye. Spectacle lenses, when measured in effective power, give the true corrective effect upon the eye when worn at the same distance as the trial lens. There is provided in *effective power* a universally adaptable unit for the measurement of the true corrective effects of ophthalmic lenses, for it is applicable to both professional and shop practices. Prescriptions may be accurately written and as accurately filled and checked up through the use of modern instruments which measure lenses in terms of effective power.

Editorials

The Line of View in Retinoscopy

IN the article on *Some Points in Retinoscopy*, which appears in this issue of the *Journal*, Professors Laurance and Wood have recorded some of the fundamental truths underlying retinoscopy or skiascopy. Reference is made to the fact that the estimation of the refraction can best be made by the reflex obtained from the macula itself, but that without mydriasis the attempt to see the macular reflex is nearly always attended by failure.

Direct retinoscopic examinations may be made along the line of vision by those using cycloplegics. Mydriatics, in the true sense of that word, would not suffice, for the eye must be under a complete cycloplegic when the patient is directed to look at the mirror held at the usual working distance of a meter or less if any *static* finding of value is to accrue to those whose routine includes retinoscopic tests under a cycloplegic. We feel that we may with propriety make the remark that many who employ cycloplegics in refractive work do not make a few simple and quick retinoscopic (or skiascopic) findings to determine whether or not the eye is completely under the influence of the cycloplegic. If the eye is not completely under such an influence, we believe that the procedure of having the patient look at the mirror so as to make the retinoscopic findings along the line of vision is considerably at fault, for accommodation will be involved to a greater or lesser degree as the case may be, and therefore the findings will not give data which these methods of procedure are presumed to give. Irrespective of the various views held by different practitioners as to the use of cycloplegics, the writer feels that all will agree to the statement that, if the eye under examination is completely

under the influence of a cycloplegic, the *astigmatic* findings as found by test along the line of vision will be, all other things being equal, more accurate than when the examination is made at an angle as is commonly necessary in static retinoscopic examinations when no cycloplegics are employed.

This statement has nothing to do, *per se*, with the matter of superiority or inferiority of cycloplegics in ocular examinations, but is a statement based upon the well-known law of physical optics that any lens when tilted or rotated about an axis is equivalent to a combination of a sphere and a cylinder. Many others believe that dynamic skiametric tests, in which examinations are made along the visual line, afford accurate findings upon the astigmatic errors, although all who use dynamic skiametry do not agree as to the interpretation or value of the total—spherical and cylindrical—findings obtained. Hence those who use cycloplegics and make retinoscopic examinations along the line of vision ought to see to it that the element of accommodation is completely eliminated if they are to record their retinoscopic findings as those obtained under a cycloplegic; whereas those who employ no cycloplegics and make the skiametric measurements with the subject's fixation at close points, make these examinations along the visual line but do have the factors of both accommodation and convergence present and must therefore interpret the differences obtained by these methods as compared with static retinoscopic findings.

A very simple device, however, will permit all those who make refractive examinations, irrespective of their routine or general methods of procedure, to carry on their retinoscopic examinations along the visual line. The device is commonly referred to as the macular reflectoscope. Its inventor is unknown to the writer; we do know that Mr. John Eberhardt of Dayton used a form of this device years ago; Dr. Armbruster of Denver has used it in conjunction with an instrument of his own invention but in a different

position. Fundamentally, the device consists of two small plane mirrors, mounted on a suitable support and placed parallel to each other, but set at an angle of 45 degrees with reference to the supporting bar. These mirrors and bar to which they are attached can be suitably mounted on a floor stand or placed upon a sleeve which can be moved along the rod ordinarily attached to the phoro-optometer or ski-optometer or any similar instrument. The rod supporting the mirrors should also be capable of rotation in such a manner that the image of a distant object, such as a test letter, can be reflected from one mirror into the other, and thence reflected into the eye to be examined. The examiner may then proceed to make a retinoscopic examination of the eye along its line of vision, practically speaking. This simple scheme is worthy of investigation on the part of those who desire to make as accurate retinoscopic tests as possible.

The Necessity for Modern Testing Instruments and Equipment in Ocular Refraction

I REMEMBER very distinctly an incident in my life when my years were considerably smaller in number than they are as I write these words. Two of us were travelling by horse and wagon to do some advertising for a county fair, and as night came on we reached a fair-sized town and drew up in front of what to me then was a rather formidable and expensive looking hotel. There was some hesitation in my manner and in my speech, and my companion, much older than myself, evidently read my thoughts for he spoke up sharply: "Take the bags right in; there is nothing too good for us." He was right—nothing is too good for the man who works and who wants to work efficiently and to the best advantage. And so perchance, if I were again in my twenties and should be engaged in

the business of demonstrating high grade instruments for eye examination, I should stop in front of your office or place of business—and that last word is perfectly clean if you and your practices are clean—and should, like my companion of years ago, speak up promptly: Take these instruments right in; there is *nothing too good for this worker.*

And what would have been considered good and proper years ago in any line of work would be dubbed obsolete and in the "has been" class today. I cannot imagine any one of you believes in the use of candles to light your home or your office today. Years ago the candle was a most valuable instrument for illumination purposes and still is as a last resort, but who would compare its efficiency with the modern incandescent lamp?

Occasionally as we walk the city streets we see an automobile or car of the vintage of ten or fifteen years ago—and smile! We know it is not to be classed in any way with modern automobiles from the standpoint of efficiency of operation, ease and pleasure of driving, comfort in riding, or wholesomeness of appearance.

If you go into the Grand Central station in New York you will see the first engine which was run on the Mohawk railroad. A wonderful thing in its day: but not to be thought of in the same class as the modern "flyer." You would not choose to do your journeying in a coach drawn by that first engine.

And yes, in the household—the broom and the wash-tub. How necessary! No—how useless and unnecessary and what a crime, when vacuum cleaners and washing-machines do the work better, quicker and relieve the human machine.

All this and countless other illustrations point to the fact that *good instruments make for progress in every sense of the word.* Then why should the practitioner upon the eye consider himself to be in an exempted and isolated class, and expect to *make progress without modern instruments?* To be sure a good workman can do much with few and inferior tools. But how much more can he do with good

tools! With poor or antiquated tools, inaccuracies creep in, time is wasted, and the workman is often discredited and faith in his ability lost, and in the end the workman is likely to lose faith in himself, as he compares his equipment with that of his fellow engaged in the same kind of work.

And again, did you ever hear of a workman who used every tool every minute of the working day? Does he not have special tools which he uses when occasion demands and which are priceless to him when he needs them? And does he not have various tools with which he may accomplish the same end, so that if one does not serve him, another will; thus assuring him and those who come to him a final and highly acceptable piece of work?

And as with everybody else, so with the practitioner upon the eye, for new and modern instruments stimulate him to better and more accurate work. For is it not true the world over that an instrument or machine, which looks and performs as though it was right and would do the work required correctly, is a source of gratification and a joy to the heart, and an open invitation to get it and get results?

So, in general, "has been" practitioners and "has been" apparatus live together; the wide-awake progressive worker knows and feels that there is *nothing too good for him* and that the best insurance against the "rust" and the "has been" state lies in modern equipment with modern methods of usage. And that which aids the practitioner in getting the best work done always instils in the mind of the person served tenfold confidence in the work being done. To do good pieces of scientific work, and to have those who receive the embodiment of this work in that which serves them believe in its goodness and appreciate it—these are the two foundation stones upon which every practice must be built.

So we feel that the best testing instruments and equipment are none too good for us and that we need them. And, in a general way, what are they? A high-grade test cabinet or proper acuity testing chart, an ophthalmometer, the best of retinoscopes and ophthalmoscopes, the latest

muscle testing equipment, a standard trial lens set and trial frame constitute the fundamental equipment from the refractive standpoint. To these each practitioner may add as his own inclinations and methods of practice dictate and warrant. Amongst these may be mentioned sphygmomanometry, perimetry, stereo-campimetry and color testing. And after a skilled examination has been made and all manner of data recorded, is it not essential that the prescriptions shall be accurately carried out in the material articles, known as eyeglasses and spectacles, delivered to those who come to you for advice and service? That the results of the care and skill of ocular examinations may be accurately measured in our trial frame prescriptions and finally delivered to us in the wearer's lenses, it is essential that each office possess a modern lensometer, or instrument which will give the true effective or vertex power.

Within the past few years (and in some cases, months) all of these fundamental pieces of equipment have been vastly improved and widened in scope of application or accuracy in data obtainable or ease and quickness of operation. Money invested every year in the best of instruments is one of the best assurances of better service to ourselves and those who come to us. The public need advice and scientific examinations and they are usually fairly good judges as to whether they receive it or not. Surely it is high time that every practitioner upon the eye took heed to his "doctrine" and his methods in order that those who come for assistance may not do so with extreme uncertainty and much credulity and often go away feeling that they have been robbed from the standpoint of service and loaded with expensive merchandise. To my mind, the emphasis in every way, fees included, must be laid upon the element of service and skill and the material things must be kept in the background except in so far as they are the media by which proper assistance can be rendered. Up-to-date offices and proper equipment are legitimate aids to proper professional service.

Some Points on Retinoscopy

Lionel Laurance and H. Oscar Wood

THE term "retinoscopy" is really a misnomer, because, in this particular method of objective test for refractive error, the retina is not seen at all. In fact, the retina, in health, is transparent, any opacity rendering it visible being due to some disorder, such as detachment. The American term "skiascopy," that is, "shadow seeing," is also inapplicable, for actually there is no shadow. What is actually visible is an image of the illuminated pigmentary ground of the choroid, known as the reflex, which, in the ordinary European individual, appears as an orange-reddish colour. Rotation of the mirror causes this illuminated patch on the choroid also to move, according to the nature of the mirror and the degree of ametropia, and it is the natural non-illuminated portion apparently following up behind that has given rise to the idea of shadow movements.

The Pupil

Ordinarily the pupil of an observed eye is black, this fact being due to the law found in conjugate foci whereby object and real image are interchangeable, *i. e.*, light diverging from the one converges to the other, and *vice versa.* From this it will be seen that if an eye observes a bright source, such as a candle, the light returning from the real image on the fundus is refracted by the ocular system and returns as a bundle of convergent pencils to the candle itself. A second person endeavouring to catch any part of the returning lights fails to do so for two reasons; either his head is interposed in front of the candle and therefore the light from the candle is cut off, or if it be placed behind the candle the latter itself forms the obstacle. Again, if two people observe each other's eyes, on each macula there is formed an image of the observed pupil,

which itself is black, and even if we include a small part of the surrounding face there is insufficient light from it to cause any appreciable illumination of the opposite fundus. Occasionally, however, a glimpse of the reflex is possible without the use of the retinoscope or similar means. Such occurs where the pupil of the observed eye is exceptionally large in proportion to the length of globe, or, to use a photographic expression, where the eye has a large "aperture-ratio" or F/No. This occurs in children and many animals such as dogs and cats. For example, if we stand back to the light and look toward a cat which has its eyes turned in our direction, a brilliant greenish reflex is observable. This, however, is only possible with artificial light, where the pupil is not unduly contracted. Undoubtedly this phenomenon has given rise to the popular notion that the eyes of cats and similar animals are self-luminous, and therefore that such animals can see in the dark. We also read that travellers and explorers in the forest or jungle, when seated round the camp-fire, can detect the presence of watching animals, who are betrayed by the two bright globes of light which one skilled in such matters, supposing him to be of the party, would call a pair of reflexes. A rather more prosaic example is found in the small bull's eye, backed up by a bright red ground, that is attached to the rear of cycles, the reflex from which gives warning to the overtaking motorists, whose headlamps supply the necessary illumination.

In practical retinoscopy, in order that the reflex may be easily seen, the observed eye must approximate very nearly with the line joining the source and the observed pupil, and to carry this into effect a mirror of some type is necessary. That generally employed is simply a silvered mirror, plane or concave, with a central aperture, about 2 mm. in diameter, either perforated right through the glass, or formed by leaving a patch of this size unsilvered. The latter method is preferable, as the edges of a complete perfo-

ration, unless rendered dead black, are apt to cause a "ghost," which, besides being annoying, actually reduces the observer's powers of vision. In the unperforated type the same thing will happen unless the unsilvered portion be kept clean and free from dust.

The Mirror

It is generally conceded that, for all-round work, the plane mirror is superior to the concave, although the latter presents advantages in certain cases. For example, in high myopia, where the reflex is very dull, the real image formed by the concave mirror is more nearly in the neighborhood of the far point, and therefore the fundus illumination is better defined, which means that the reflex is rendered brighter. This applies also to the long focus concave, which throws a convergent pencil into the eye. The long focus type is particularly valuable in cases of high hypermetropia, in which the far point, being virtual, closely coincides with the real image that would be formed by the mirror were the subject's head not interposed. It is not impossible to use a convex mirror—indeed when near the point of neutralization it presents a distinct advantage, as the virtual image formed by it is nearer to the far point. In other conditions, however, the illumination would be too poor, and in high errors the reflex would be altogether invisible.

It is important to realize what is meant by the *source* in retinoscopy. This is not the original lamp, which is immovable, but is its image formed by the mirror. This image and the fundus illumination are therefore conjugate foci, and, apart from the apparent movements of the reflex caused by the various rotations of the mirror, the function of the mirror ceases after it has projected the necessary light into the observed eye. In other words the *nature* of the mirror has no influence whatever on the actual measurement of the refraction, as the point of neutralization is attained by the same lenses in any particular case for any type of mirror.

The reflex, as seen by the observer, is either the real or virtual image of the fundus illumination appearing as a reddish glow filling more or less the area of the observing pupil. That is to say, the observer is really viewing the *far point* of the eye under test, which may be actually situated at any distance, real or virtual, according to the refraction. Thus in myopia it is real, and may be in front of, or behind, the observer; in emmetropia it is at infinity, and in hypermetropia it is virtual, that is, behind the observed eye. This fact is not at all apparent, as in all cases the glow appears in the plane of the pupil. This apparent anomaly is explained by the fact that the observer's eye insists on projecting the intangible far point to the nearest tangible object, which happens to be the observed pupil. To illustrate the point, if one holds a strong convex lens considerably in excess of its focal length from one's eye, a distant object appears inverted. What is actually seen is the aerial real image formed *between* the lens and the observer, but instead of it being seen as in that position, it appears to fill the lens, that is, to occupy the plane of the lens itself. Here the mind projects the intangible aerial image to the nearest tangible object, the lens. On the other hand, if the real image be projected on to a finely ground glass screen, rendered semi-transparent by being moistened with water, the mind immediately identifies its position with that of the screen, which is the nearest tangible object.

The Reflex

It is important to realize this refusal of the mind to project the reflex to its actual position. It follows that the observer's eye is, throughout the test, accommodated for the observed pupillary plane, and therefore details of the fundus are never visible, except in high cases of errors and a large pupil accompanied by accidental change of the observer's accommodation for some plane in front of,

or behind, the pupillary plane. Even should a fundus detail be thus visible, it is seldom recognized as such owing to the enormous magnification, a single vessel appearing a quarter or even half of the width of the pupil. This magnification is in inverse proportion to the amount of error, and partly explains the fact already mentioned, that details may be picked up easier in high departures from emmetropia. It is infinite when the observer has reached the point of neutralization.

The reflex, as a whole, follows the same rules. It is small in high errors, expanding as the correcting lenses are put up, and finally fills the whole pupillary area when the point of neutralization is actually, or approximately, reached. This accounts for the so-called reflex "band" accompanying high simple hypermetropic or myopic astigmatism, or at any rate those conditions where the one meridian has a low error compared with the other. In the meridian of high error the reflex is less than the width of the pupil, and in the meridian of low error it fills the pupil, hence the band-like appearance of the reflex whose movements are so easily followed.

The Fundus

It is interesting to note the area of fundus illuminated by the ordinary retinoscopic equipment consisting, say, of a plane mirror and lamp having a diaphragm of about one inch in diameter. Presuming the mirror to be used at the usual distance of one metre, the image of the lamp aperture is also formed one metre behind the mirror, and therefore two metres from the observed eye. We have therefore an object one inch in size at a distance of two metres, and working from the usual expression giving the size of retinal image, the size of the fundus illumination is:—

$$S = \frac{15 \times O}{f_1} = \frac{15 \times 1}{2000} = .0075 \text{ in.}$$

or rather less than one-fifth of a millimetre. This affords some idea of the apparent size of the reflex as seen by the observer when we remember that, even where we have not actually secured the point of neutralization, it easily fills the average pupil having a diameter of, say, 5 mm. demonstrating a magnification of some 30 times.

As with the size of the reflex, its intensity and speed of movement—for a given rotation of the mirror—are also inversely proportional to the refractive error of the observed eye. In fact, at the point of neutralization all three are maximum. With regard to movement we interpret this as the transition from one type of apparent motion to the reverse, so that, denoting one kind by the + sign, and the other by the — sign, we see that, at the point of neutralization, the movement is neither + nor —. In other words, infinity in this sense can be considered either + or —. A similar idea obtains when an object is placed at the principal focal point of a convex lens. We may then consider the refracted parallel light as forming either a real or + image at infinity on the opposite side of the lens to the object, or a virtual or — image at infinity on the same side as the object.

As stated, the function of the mirror is limited to providing the fundus illumination; the part it plays in producing the "with" and "against" movement of the reflex is incidental, its nature having no influence at all upon the measurement of the refractive error. In practical retinoscopy we are concerned with the course taken by the light emerging from the eye, after it has been diffused by the choroid, and, therefore, in treating of the reflex movements, as controlled by the refraction of the observed eye, and also in diagrams depicting them, it is better to divide the conditions into two distinct parts, as confusion may arise if this is not done.

The Movement of Reflex

The *effective* source of light is the image of the lamp formed by the mirror, and may be situated behind it, or between it and the eye, according as it is plane or of the ordinary concave type. By ordinary concave we understand that of about 10 in. focal length, so that the effective source, that is the real image of lamp, is between observer and observed. With the plane mirror we may include the long focus concave, and the convex, were the latter of practical utility. However, as stated, the point of neutralization for any particular case is attained with the same lenses irrespective of the mirror, but there are a number of possible combinations of movements between those due to the various types of mirror and errors of refraction. This point is better realized with the aid of two or three diagrams, as follows:

Suppose the mirror to be plane, and hold at the conventional distance of one metre. Let there be in the observed eye some degree of hypermetropia—the amount is immaterial.

In Fig. 1, let L be the lamp, and M the plane mirror, producing the virtual effective source S, which in turn has its conjugate real image I on the fundus of the observed

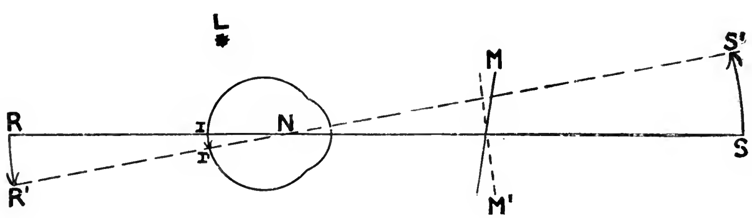

Fig. 1

eye. This real image need not necessarily be sharp — in fact, in general it is blurred. The only case where it could be sharp would be in myopia of a degree such that the far

point coincided with S, accommodation being at rest.

It will be noticed that no rays are shown in the diagram; they are unnecessary, and indeed confusing, because, as will be seen, we have only to apply the principles of ordinary conjugate foci to demonstrate what is finally seen by the observer.

Now imagine the mirror tilted downwards into the position M′; the effective source S will then move upwards to S′. The actual fundus image I, being real, will move in the opposite direction, *i.e.*, downwards to I′, as though both S and I were at opposite ends of a bar pivoted about the nodal point N. The observer behind M sees, not the actual image I, but its virtual image R formed at the far point of the hypermetropic eye. R is the reflex, and being virtual moves in the same direction as I, that is, downwards towards R′. The reflex is therefore said to move "with" the mirror. As previously pointed out, R is not conceived to be in its position as shown, but to occupy the pupillary plane of the observed eye, for which the observer is accommodated.

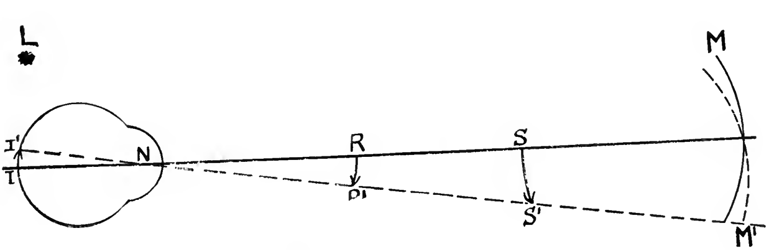

Fig. 2

Again, let the mirror be of the ordinary concave type, and the error of refraction a myopia of 4 D., the observer standing at 66 cms. If the lamp is not nearer than 66 cms., the real image constituting the effective source is formed in front of the observed eye. The far point of

the eye being 25 cms., is also situated between subject and observer.

As in the last illustration, suppose the mirror M (Fig. 2) to be tilted downwards into the position M′. The effective source S also moves downwards to S′, the retinal illumination I moves upward to I′, and its conjugate real image R finally moves downwards to R′. Therefore, to the observer, the reflex moves apparently "with" the mirror. Again it will be noticed how the two pairs of real conjugates, S and I, I and R, are, as it were, pivoted about the nodal point N.

A further example will illustrate the use of the long-focus concave. Suppose this to have F = 1.25 meter, and the eye to be myopic 1 diopter, the observer being at 50 cm. After reflection by the mirror, the light enters the eye convergent towards a point well behind the subject's head, and the return light will tend to focus at one meter, or 50 cms. behind the observer's head.

Again imagine the mirror to be tilted downwards (Fig. 3). The effective sources also move downwards, but as the

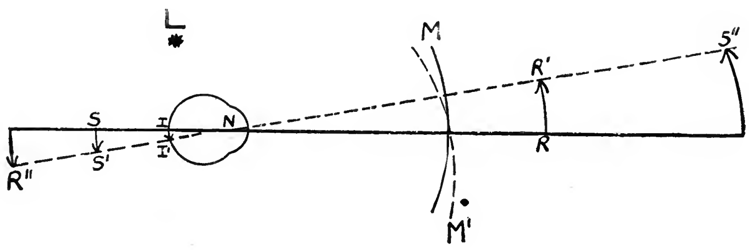

Fig. 3

light, when incident on the observed eye, is still convergent it appears to originate from some point S″ behind the mirror, moving *upwards*. Theoretically, S″ is "beyond infinity," if we may be allowed to use the term. The fundus image

I, therefore, moves downwards to I′, and its corresponding real conjugate far point R would move upward to R′ *were the observer not in the way*. As it is, the observer receives the still convergent light and refers it, again "beyond infinity," to a point represented diagramatically by R″, which appears, therefore, to move downwards. The final apparent reflex movement is therefore "with."

These three cases, although differing considerably as to their data, have been purposely chosen to illustrate how the factors of mirror and refractive error may combine to produce the same reflex movements. It is on these lines that the well known rules, upon which practical retinoscopy is based, are formulated.

The Line of View

It is a mistake to imagine that easy and accurate measurement of refractive errors is compatible only with the greatest dilation of the pupils, as under full mydriasis. To anyone accustomed to undilated pupils the appearance of the reflex, although, of course, very bright, is decidedly confusing on account of the spherical aberration disclosed towards the periphery. While the central reflex has one kind of movement, the peripheral reflex may have the opposite, and to such a degree as to absorb the attention of the observer. Needless to say, large errors are introduced if the attention is distracted from the central portions. On the other hand, very small pupils render observation difficult or even impossible. Undoubtedly the happy mean is what is usually found in practice, *i.e.*, an average pupil of about 4 to 5 mm., provided pigmentation of the choroid is not excessive.

For a true estimation of the refraction the reflex should be obtained from the macula itself, but in practice, without mydriasis, the attempt causes too much contraction of the pupil. This, however, does not altogether account for the practically total disappearance of the reflex when the observed eye looks straight at the mirror. In fact, the

subject is somewhat obscure; perhaps the shelving sides of the macular region cause a certain amount of oblique reflection of the incident light, but not to a great extent, seeing that the retina is transparent. However, it is a fact that any attempt without mydriasis to see the macular reflex is nearly always attended by failure.

It therefore remains to take the refraction as near to the macular region as possible. Whether the spot selected be on the nasal or temporal side, or below, is immaterial — that is, whether the subject be asked to look close past the mirror with either eye, or just above the observer's head, does not seem to make much difference. A downward gaze is hardly practicable, as it may bring into view some detail of the observer's person, or of the floor, which may excite accommodation. It is, however, of vital importance that the reflex be taken *as close as possible to the macula;* if not, the varying depth of the globe is bound to introduce large errors. We have only to remember that a depth change of one-third of a millimetre introduces a dioptric change of one diopter in order to realize the importance of this rule, failure to observe which undoubtedly accounts for the majority of discrepancies between the objective and subjective findings, especially with beginners. Unfortunately, the reflex is very bright and distinct when taken at the optic disc, and as the latter nearly always shelves towards the centre, the resulting error renders the measurement very inexact.

General Illumination

The best results are obtained, not in an absolutely dark room, but in a half light such as is produced by the lowering, in daytime, of ordinary venetian blinds, or those made of semi-opaque material. The refractionist can then see to move about and to pick out his lenses, etc., but more important than all, the subject is enabled to fix some point on the opposite wall. Such fixation is very essential for

two reasons; first, it prevents the eye from wandering, thereby neutralizing the care the operator has taken to keep in close touch with the visual axis; second, in a measure it enables the accommodation to be controlled. The person naturally makes an effort to see as clearly as possible, and, therefore, with the slight fog produced by the reversing or neutralizing lenses, there is every inducement for the accommodation to be as passive as possible.

It goes without saying that the eye not under test must be occluded, otherwise the accommodation in the other will not respond to the presence of the fogging lenses mentioned above. As regards the actual lenses employed in astigmatism the meridian of higher hypermetropia, or lower myopia, should be corrected first, with a spherical lens, and the balance of error at right angles by means of a concave cylindrical axis parallel with the meridian already dealt with. This procedure, while being in accord with the subjective routine, affords no inducement for accommodation. The method of using separate spherical lenses for each principal meridian is not to be advised except when the eye is under cycloplegia, in which case, of course the factor of accommodation is absent.

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Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

Samuel H. Robinson, O.D., F.O.S.

CHAPTER II (*Con.*)

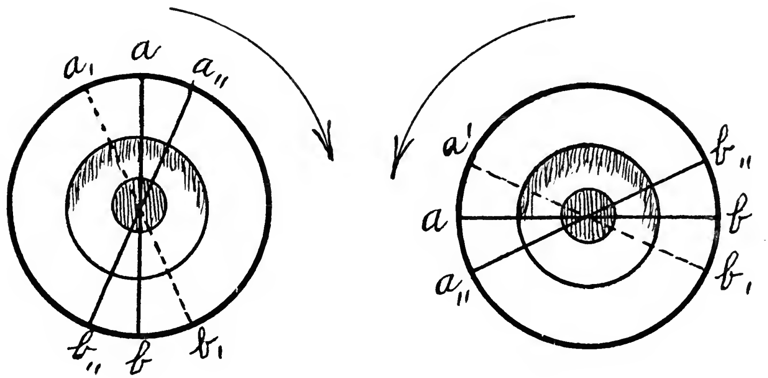
The Phoria or Muscle Tests

The Test for Cyclophoria

AFTER making the lateral and vertical muscle tests there is one other that may yet be made; it is the test for cyclophoria. This imbalance is a tendency for one or both eyes to rotate on the antero-posterior or visual axis. Figures 23 to 29, inclusive, illustrate cases of cyclophoria. In Figure 23 the vertical meridian a b is seen rotated in the direction of the arrow and the vertical image line a b which coincides with it will appear as a_1 b_1. In Figure 24 the horizontal meridian a b is seen rotated in the direction of the arrow and the horizontal image line appears displaced as a_1 b_1.

The apparently tilted image lines $a_1 b_1$ do not really assume the positions indicated in Figures 23 and 24 with respect to the geometrical perpendicular or horizontal. The image lines on the retina cannot in fact be shifted from their established positions. With respect to retinal orientation or retinal meridians, however, the image lines do change their positions. Assuming no cyclophoria to exist, the vertical meridian and a vertical image line upon the retina necessarily coincide and the mind interprets the image as vertical. Should the eye rotate in the direction indicated in Figure 23 the vertical meridian would be shifted to the position a_{11} b_{11} while the image line would still maintain its former position a b. *It is with respect to the new position of the vertical meridian that the image line*

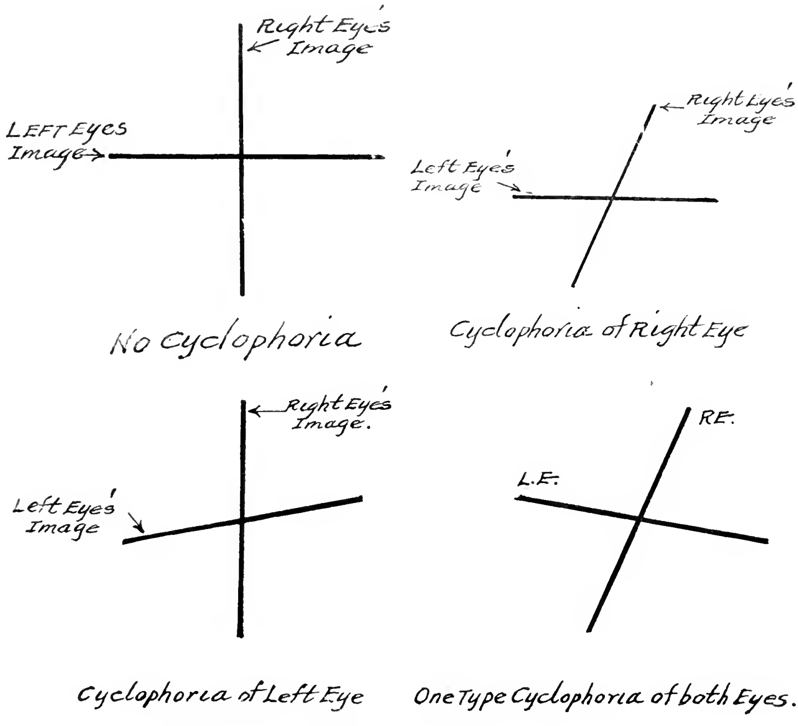
now appears tilted from its true vertical position, and this to the extent that it is removed from the new position of the vertical meridian. Thus the mind interprets a tilting of the image line upon the retina and always in a direction contrary to the rotation of the eyeball.



Figs. 23 and 24. Images and rotations in cyclophoria

A suitable method for making this test is to place Maddox rods before each eye respectively with their axes at right angles; one white and one red rod is preferable. High power plus cylinders may be used when Maddox rods are not available. To get the effect of the red Maddox rod a red glass disc may be placed behind one of the cylinders. The same can be done if one has two white Maddox rods. The two Maddox rods or high power cylinders will apparently transform the white spot on the distant chart into two lines—one white and the other red—forming right angles at their intersection. The advantage of having one red and one white line is that it assists more readily in distinguishing the image belonging to each eye. Assuming that the *red line* belongs to the *right eye* and is seen *vertically* while the *white line* belongs to the *left eye* and is seen *horizontally*, should there be no cyclophoria present the two

lines will appear superimposed in the form of an erect cross. (Fig. 25). Should, however, the *right eye* be rotated on its visual axis the *vertical line* will appear tilted in a



Figs. 25 - 28. Various conditions of cyclophoria

direction and degree dependent upon the eye's rotation. (Fig. 26). Should the *left eye* be rotated on its visual axis while the right remains unaffected, then the *horizontal line* of the cross will show a tilt, as expressed in Figure 27. Should both eyes have a tendency to rotate on their visual axes, then both the *horizontal* and *vertical* lines will appear tilted and cases similar to Figures 28 and 29, varying in degree, will become manifest.

A probably more suitable method for making the cyclophoria test consists in setting both Maddox rods, or high power cylinders, *parallel*, i.e., both vertically or horizontally.

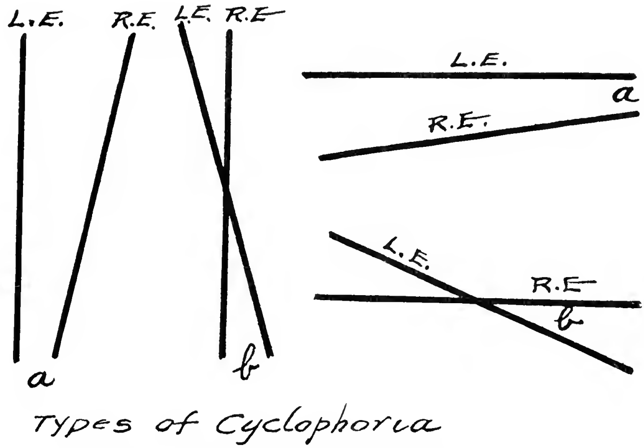


Fig. 28 (a). Testing cyclophoria with Maddox rods

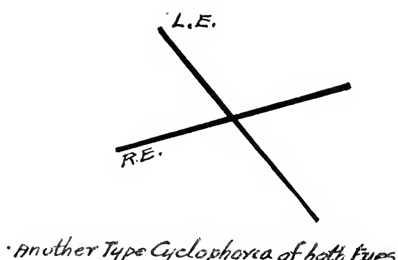


Fig. 29. Another type of cyclophoria

The slightest tilting of either line becomes quickly discernible inasmuch as the two lines do not remain in parallelism, or when intersecting, fail to coincide into one line, but form instead figures as indicated by *b*, in Figure 28a. Cyclophoria as expressed by *a*, in Figure 28 (a), suggests

the presence of considerable lateral or vertical imbalance while that expressed by *b*, indicates little or no imbalance in the lateral or vertical muscles. It is quite important, when making this test with the Maddox rods setting *parallel*, that one colored rod or a red disc be used, in order to help more readily differentiate the image for each eye.

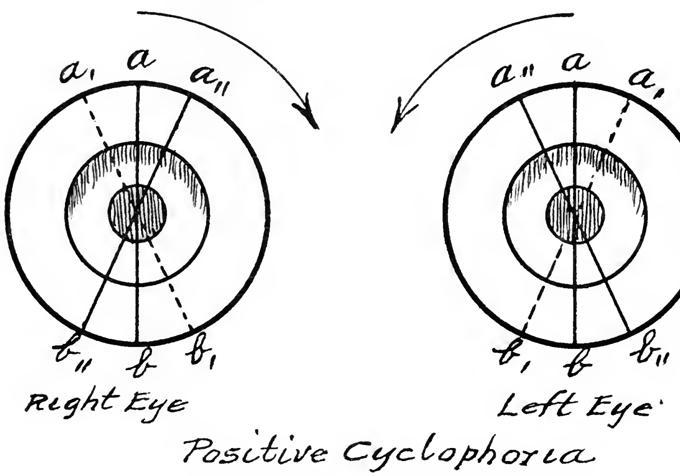


Fig. 29 (a). Positive cyclophoria

Determining the Kind and Degree of Cyclophoria

When one or both eyes have rotated on the antero-posterior axis *nasalward*, as represented in Figure 29 (a), the condition is designated *positive cyclophoria*. The mind, however, sees or interprets the image line as tilting *templeward* (as the line a_1 b_1). Should cyclophoria be due to a rotation of the eye *templeward*, as represented in Figure 29 (b), then the condition is designated *negative cyclophoria*, and to the mind the image line is seen tilting *nasalward* (as the line a_1 b_1).

The fact is, however, that the image lines focus upon the retina at right angles to the axis of the Maddox rod,

whether cyclophoria exists or otherwise. Hence the apparent tilting of these image lines expresses merely a mental interpretation due to a change in position of retinal meridians with respect to external objects, when the eye has undergone a torsion upon its antero-posterior axis.

Maddox rods, graduated to measure and express positive and negative cyclophoria, often vary in their interpretation. One type is constructed on the principle above indicated. Another is designed on the basis that positive cyclophoria indicates a rotation of either eye to the *right*, while negative cyclophoria, the rotation of either eye to the *left*. There is, however, no particular significance in the matter of interpretation. Just one condition is essential. The

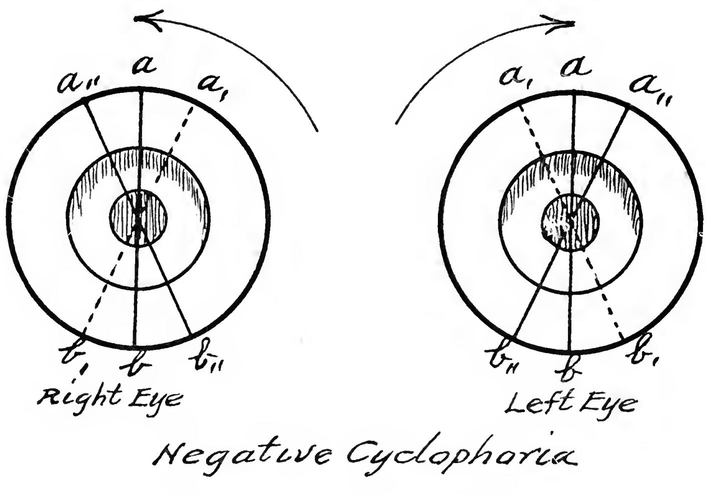


Fig. 29 (b). Negative cyclophoria

Maddox rod must always be turned so the image line falls upon the displaced vertical or horizontal retinal meridian. As soon as these coincide, the mind interprets the tilting line as straightened.

Inasmuch as the image line is always at right angles to

the axis of the Maddox rod, this axis, upon correction, therefore, will always point in contrary direction to the eye's torsion. This will be observed in the manner that the plus and minus signs are indicated upon Maddox rods (see Fig. 29c). The degree to which the Maddox rod has to be rotated to straighten an image line which tilts is a measure of the cyclophoria present. The graduations upon the Maddox rod when using one so specially designed, or those upon the trial frame when the latter is in use, will indicate in degrees the amount of torsion, or cyclophoria.

At present the author can offer no specific mode for treating cyclophoric imbalances. In his own practice, however, he has found but few such cases, which,—in accord with the views of other students of the subject,—have failed to materially subside after the cardinal muscular deficiencies—vertical and horizontal—have been compensated and the proper refractive correction has been administered.

Importance of Correction before the Eyes when Making Muscle Tests

During all muscle tests it is essential that the refractive correction be worn by the patient. The importance of

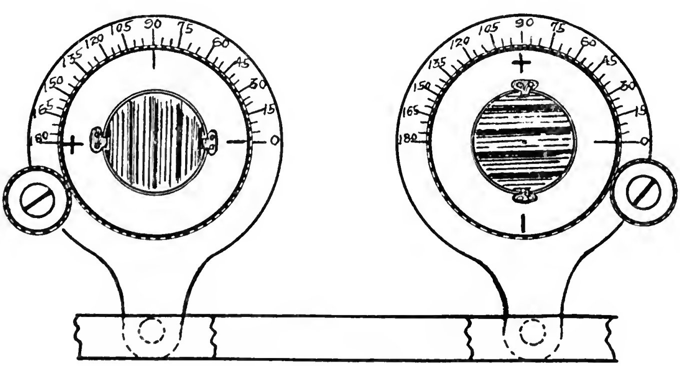


Fig. 29 (c). Plus and minus cyclophoria as indicated upon Maddox rods

this becomes self-evident—particularly in lateral imbalances —when we recall former paragraphs relating to the influence of lens corrections upon the muscle imbalances. It is the muscle imbalance ultimately in evidence, whether increased or decreased by the refractive correction, that we are called upon to correct and only as the true and complete imbalance determined by every contributary circumstance is finally established may we hope to properly diagnose or fully correct the muscular anomaly.

Lateral Muscle Tests at the Near Point

We have so far discussed muscle testing at six meters or infinity. We will now take up the same work at the near point. While the optical principles involved in making the near and distant tests are identical the methods

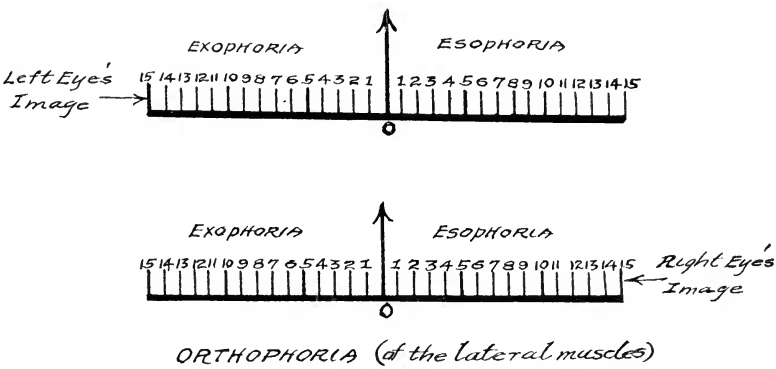
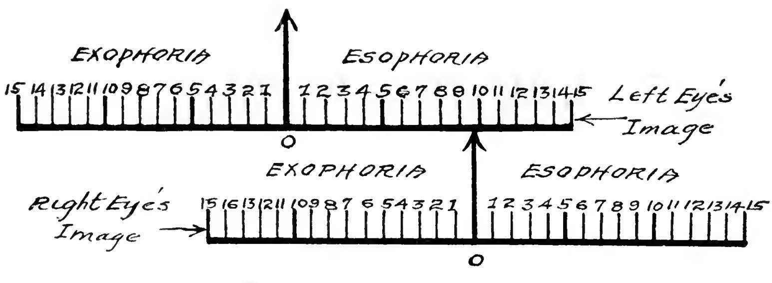


Fig. 30. Orthophoria

commonly employed by refractionists and as contained in most textbooks are somewhat different. For instance, when measuring esophoria or exophoria at the near point but few employ the Maddox rod although the same is in common use in the distant test. Instead, the average operator produces vertical diplopia by placing about six

degrees of prism apex up or down, before either eye and a scale such as represented in Figure 30 is held at the reading distance. With diplopia thus produced the patient beholds two identical scales one above the other. Assuming that the six degree prism, say *apex down*, had been placed before the *right eye* the *lower scale* will necessarily belong to that eye, since a prism, *apex down*, before the *right eye* will have caused its image to be displaced *downwardly* and the scale it beholds will necessarily appear below the other one. Thus having created two scales one above the other, they will now appear to move from right to left, crossing or separating, in accordance with the direction of pull or imbalance of the lateral muscles. Should the arrows on both scales be in a continuous line vertically (Fig. 30), there is no lateral imbalance present. Should the *lower scale* belonging to the *right eye* be to the right of the upper scale, it would indicate



ESOPHORIA.

Fig. 31. Condition of esophoria at the reading distance

the eyes have turned *inwardly* (since the images have separated each on its own side) and the condition would be one of esophoria (Fig. 31), the amount being indicated by the lower arrow against the upper scale. Should, on the other hand, the *lower scale* belonging to the *right eye* be to the left of the upper scale, it would indicate that the

eyes have turned *outwardly* (since the images have *crossed* to the opposite sides) and the imbalance must then be exophoria, represented in degrees by the lower arrow pointing to the degrees on the upper scale (Fig. 32).

Vertical Muscle Tests at the Near Point

In like manner, to test for vertical imbalance, we break up fusion by placing about ten degrees of prism, *apex out*, before, say, the right eye producing lateral or horizontal diplopia. Figures 33 and 34 show a scale that may be used for measuring vertical imbalances at the near point. A 10 degree prism placed *apex out* before the *right eye* will displace its image *outwardly* or to the *right*. Hence its image will appear as the right one of the two developed by the prism, and the eye which has a tendency to turn *upwardly* will see its scale correspondingly *lower* than its companion eye.

In right hyperphoria then (see Fig. 33), the *right scale* belonging to the *right eye* will appear lower than the *left scale* belonging to the *left eye*, and the left arrow, pointing to the right scale, will indicate in degrees the amount of right hyperphoria present. Should the *left scale*, belonging to the *left eye* be the *lower one*, then that eye would necessarily be pointing *higher* than its fellow eye (since its image is *lower*), and the condition would be left hyperphoria, measured by the left arrow against the right scale (Fig. 34).

Careful and repeated reading of the foregone matter, if not clearly comprehended, will gradually establish the principles involved; and tests, such as described, may ultimately be made, not from stereotyped rules, but from a fundamental understanding. Knowing how the eyes rotate with respect to prisms, and how images behave with respect to the rotation of the eyes, one can set his prisms according to plan or a fixed purpose, and conduct his investigations with greater assurance and intelligence. While that clear and thorough understanding, so much desired, may not

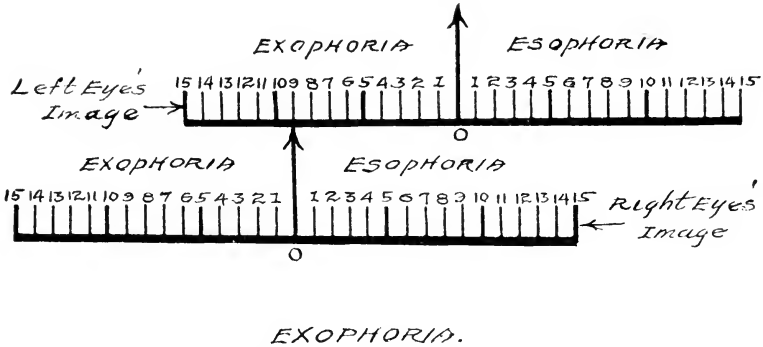
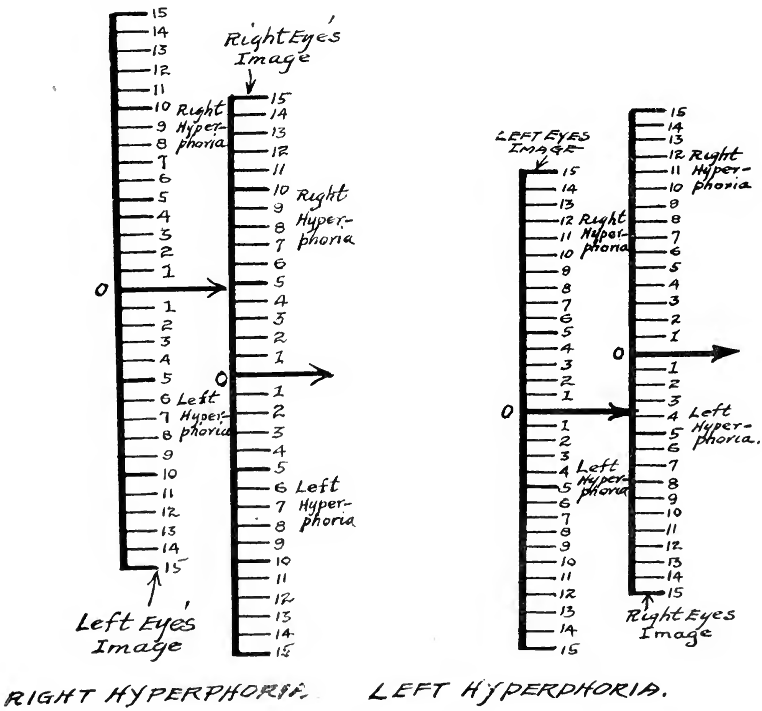


Fig. 32. Condition of exophoria at the reading distance



Figs. 33 and 34. Hyperphoria

be acquired at once, after reasonable diligence, the same may be fully assured.

The Author's Near Tests for Muscle Imbalance

Although the above method for measuring muscle im-

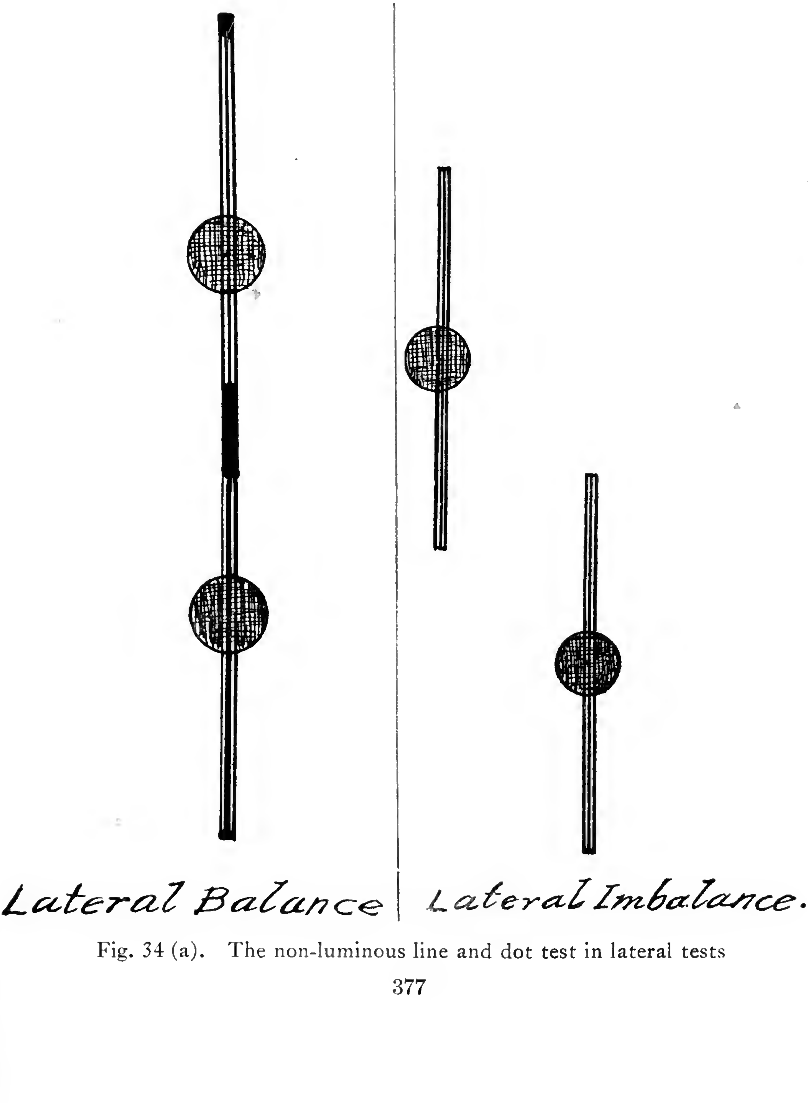


Fig. 34 (a). The non-luminous line and dot test in lateral tests

balance at the near point is commonly in use, there are other methods just as efficacious. The non-luminous line and dot test (Fig. 34a), used both for near and distance, is practical and is utilized by many practitioners. The principle underlying this test is similar to that covering the scale test just described. The difference lies in the fact that readings are taken from the prisms held before the eyes instead of the graduated scale in the hand of the patient. In this latter test, the amount of prism power necessary to bring the two lines and dots into one continuous *vertical line*, measures the esophoria or exophoria present (*apices in* for esophoria, and *apices out* for exophoria), and the prism power necessary to bring the lines and dots into one continuous *horizontal line* is a measure of the right or left hyperphoria present (*apex up* before *right eye* for right hyperphoria, and *apex down* before *right eye* for left hyperphoria).

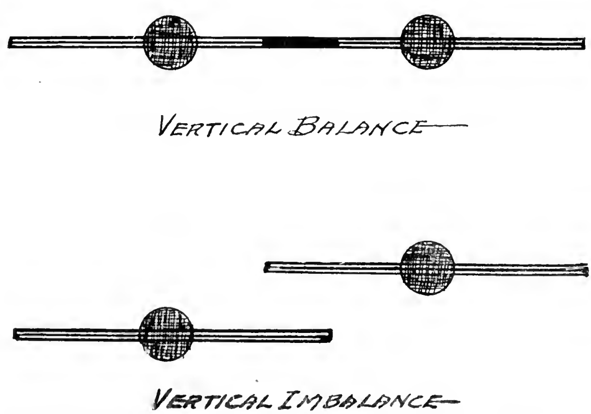
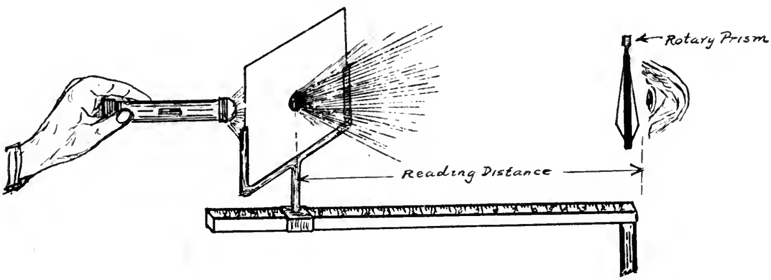


Fig. 34 (b). Non-luminous line and dot test in vertical tests

The author has, however, in his own practice, seen fit to adopt a method for near testing which is a replica of the distant test described on former pages. It is likewise a

luminous test, but not quite as subjective as the scale and arrow test. It consists of letting the patient look at a perforation or hole in a card held at the reading distance (See Fig. 35). Through this small opening the operator



THE AUTHOR'S NEAR MUSCLE TEST.

Fig. 35. Author's method for near-muscle tests

directs the light from a luminous retinoscope or flashlight. This provides a luminous source at the near point similar to the luminous spot on the distant chart. With red Maddox rod and prisms we can now make the same tests at the near point that we formerly made at the distance. The advantages of this test are as follows:—

1 A luminous test always engages better attention and a stronger concentration on the part of the patient.

2 Inasmuch as the operator manipulates the prisms he needs but consult his patient in the matter of determining when the two images meet. In the scale and arrow test, the patient himself reads the scale and reports to the operator his findings. Through the patient's confusion or stupidity many errors creep into such testimony.

3 A uniform test for near and distance plants the operator firmly in a mode of procedure which gradually becomes second nature to him.

4 Tests by the luminous method may be made as accurately and quickly at one reading distance as at another. The scale and arrow test, to be strictly accurate, requires that the graduations be re-designed for every near distance at which the test is made.

Again, let it be remembered, that this near test is made exactly like the distance test. The red Maddox rod breaks up fusion by converting the white spot into a red line before one eye, while the uncovered eye beholds the white spot unchanged. In the distance test the point of fixation is at six meters, while in the near test, it is at the reading distance.

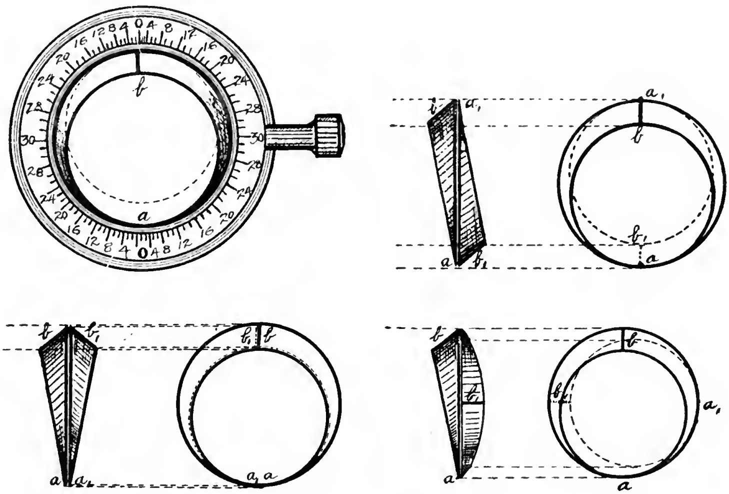
The Rotary Prism—Its Purpose

Every refractionist is familiar in name at least with the double rotary prism. It may not be amiss, in preparation for its use, to become better acquainted with its purpose and structure. The object of the rotary prism is to provide variable prismatic power by the turning of a thumb screw. To obviate the difficulty of continually extracting from the trial frame prisms that must be constantly supplanted by others of greater or lesser power, the rotary prism—which can remain undisturbed before the eye, and can be quickly adjusted to any desired power—has come into welcomed use.

In performing duction tests or giving muscle treatments, the rotary prism thus becomes practically indispensable. The steadily increasing pull, made possible by the rotary prism, is essentially helpful from the standpoint of both patient and operator. The interruptions in stimulus and mechanical technique, when a series of individual trial frame prisms are employed, make their use inadvisable if not prohibitive. Should the operator lack in his equipment the phorometer which is provided with one or two rotary prisms, he would do well to supply himself with at least one of these prisms, which may be inserted in the regular trial frame. Thus equipped, he can perform practically any portion of ocular muscle work.

The Rotary Prism Described

The double rotary prism consists of two circular prisms, generally 15 degrees each, held together by a light frame, so that both prisms can be revolved in opposite directions by means of a thumb screw or milled edge screw. The



Figs. 36-39. The rotary prism

prisms thus rotating in apposition develop a variable prismatic power, from zero (when the bases or apices are in opposite direction) to 30 degrees, their combined value (when the bases and apices are respectively together). A graduated circular scale, followed by a base indicator, registers at every turn the amount of prismatic power developed (See Fig. 36). To further describe the rotary prism we will refer to Figs. 37, 38 and 39. In Fig. 37 we find the *apex* of one prism lying beside the *base* of the other. In this position the prisms neutralize each other and their combined value becomes *zero*. In Fig. 38, the *apices* and *bases* of both prisms lie respectively together; their combined

value becomes the sum of their prismatic power or 30 degrees. Figure 39 shows another combination of the two prisms, this time with apices or bases at right angles. By a form of calculation every angular combination of the two prisms has been computed and the prismatic power determined has been marked and indicated as expressed by the circular scale to be found upon each rotary prism. This type of prism, most generally in use, is known as the Risley rotary prism (Fig. 36).

How to Measure Esophoria and Exophoria with Rotary Prisms

We have heretofore discussed ocular muscle tests without giving a detailed mode of procedure. To give the reader a tangible idea of how to proceed in this work we will refer to Fig. 40.

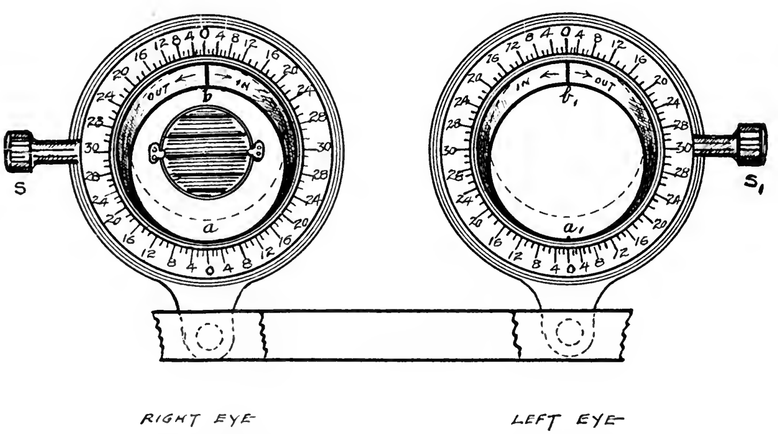


Fig. 40. Rotary prisms in lateral muscle testing

To test for esophoria or exophoria, set a Maddox rod *horizontally*, say, before the right eye. In addition to the Maddox rod, set one or two rotary prisms before the eyes

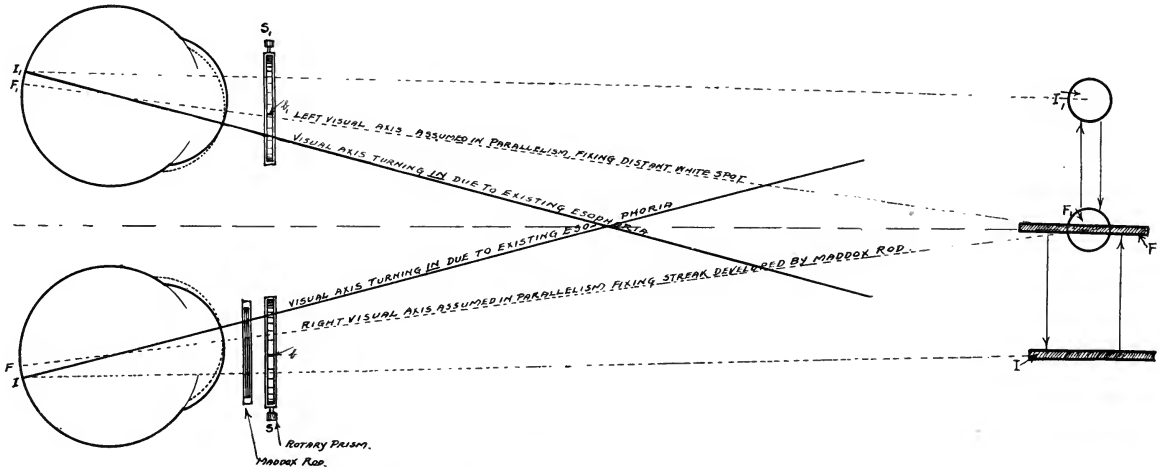


Fig. 40a. The displacements FI and F_1 I_1 upon the retinae are responsible for, and equivalent to, the separations of images from F to I and from F_1 to I_1 in space. By shifting, by means of rotary prisms before the eyes, the displaced images I and I_1 back upon the foveae F and F_1, the projected images I and I_1 in space will likewise be shifted back to F and F_1 as though the axes were in parallelism. The eyes, however, maintain their convergency or divergency. The prisms rotated into position, merely neutralize or correct the separation of images due to the eyes rotation by uniting them—hence such prismatic power becomes the measure of the eyes' deviation or imbalance.

with thumb screws S and S_1 *at the sides*, and the bases b and b_1 at *zero*, and *vertically*. In that position the prisms act as planos, exerting no influence upon the eyes. The Maddox rod, however, converts the white spot on the distant chart into a *vertical* line or streak. Fusion is thus destroyed, inasmuch as the right eye beholds a vertical line and the left eye the white spot unchanged. The eyes roam now in a direction guided by the imbalance.

Assuming the imbalance to be esophoria, the eyes will be turning *inwardly* and the images, moving in opposite direction, will *separate*, i.e., the line belonging to the right eye will appear to the right in the field of vision, and the white spot, belonging to the left eye, to the left in the field of vision. To measure the extent to which the eyes have turned *inwardly*, we need but determine how far the images in space have moved in contrary direction, or *outwardly*. By rotating prismatic power before the eyes (*apices in* or *bases out*) sufficient to unite the images, *i.e.*, sufficiently so that the images are drawn back *inwardly* and united, we have a measure of the extent to which the eyes have turned *inwardly* in order to have produced the original *outward* displacement of images. (See Fig. 40a.) *The amount of prismatic power, apices in, before both eyes, necessary to thus unite the images is a measure of the esophoria present.*

Likewise, to measure for *exophoria*, we need but remember that the eyes are turning *outwardly*, hence the images, turning in contrary direction, have moved *inwardly* and are *crossed*, i.e., the *line* belonging to the *right eye* will appear to the *left* in the field of vision and the *white spot* belonging to the *left eye* over to the right in the field of vision. Prisms, *apices out*, are now rotated before the eyes, with increasing power until the images that are *crossed* through the *outward* rotation of the eyes are now brought back and united under the influence of the prisms and in the direction of their *apices*. *The amount of prismatic*

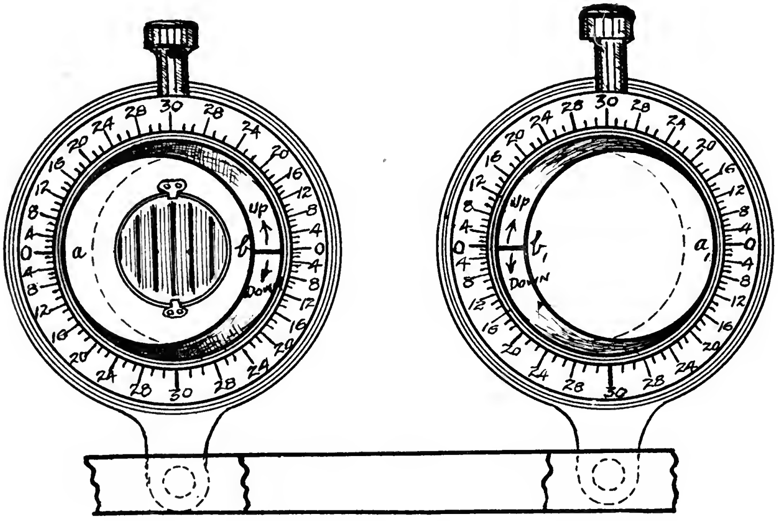
power, apices out, before both eyes thus necessary to unite the images is a measure of the exophoria present. An excellent method for becoming quickly familiarized with the behavior of images and the operation of the rotary prisms is to place oneself behind the prisms and Maddox rod, executing rotations of the prisms and studying corresponding movements of the images. Throughout the study of ocular muscle work the author resorted to such practice.

How to Measure Right and Left Hyperphoria with Rotary Prisms

Measuring right or left hyperphoria with rotary prisms is similar to measuring esophoria and exophoria, with the exception that the Maddox rod before the right eye must be set *vertically* instead of horizontally so that a horizontal line—as one image—will be available, affording thereby a knowledge of the vertical balance from the position of the other image (white spot), according to its location *above* or *below* this line. (See Fig. 41.) The prisms also are set so that the thumb screws S and S_1 are *at the top* instead of *at the sides* and the base indicators b and b_1, again at *zero*, are now *horizontal* instead of vertical. With indicators in this position, *apices* or *bases* may be turned *up* or *down* as is necessary in measuring vertical imbalances.

Should right hyperphoria exist, the right eye will be directed *upwardly* and its image, the *line*, will correspondingly appear *lower* or *below* the *white spot*, the image of the companion eye. Should left hyperphoria be present, the left eye will be directed *upwardly* and its image, the *white spot*, must necessarily be *lower;* hence the *line* will be *above* the *white spot.* In measuring right or left hyperphoria, therefore, a prism is rotated *apex up* before either eye respectively until the *line*, the image of one eye, unites with the *spot*, the image of the companion eye. In each respective case the indicators on the prisms will show the measure of right or left hyperphoria. The simplest way

to measure vertical imbalance is to use but one prism at a time. Should the condition be right hyperphoria, it is but necessary to rotate the prism before that eye, *apex upwardly* (base downwardly). The other prism, before the left eye, remaining at zero, has no influence whatever and may be assumed to be negligible, or as though it were not before that eye. Similarly, should the imbalance be left hyperphoria, it is but necessary to rotate the prism before the left eye, *apex upwardly* (base downwardly),



RIGHT EYE LEFT EYE

Fig. 41. Rotary prisms in vertical muscle testing

leaving the prism before the other eye at *zero* and undisturbed. The amount of prismatic power, *apex up* (base down), before the *right eye* necessary for the line and spot to intersect is the measure of the right hyperphoria present;

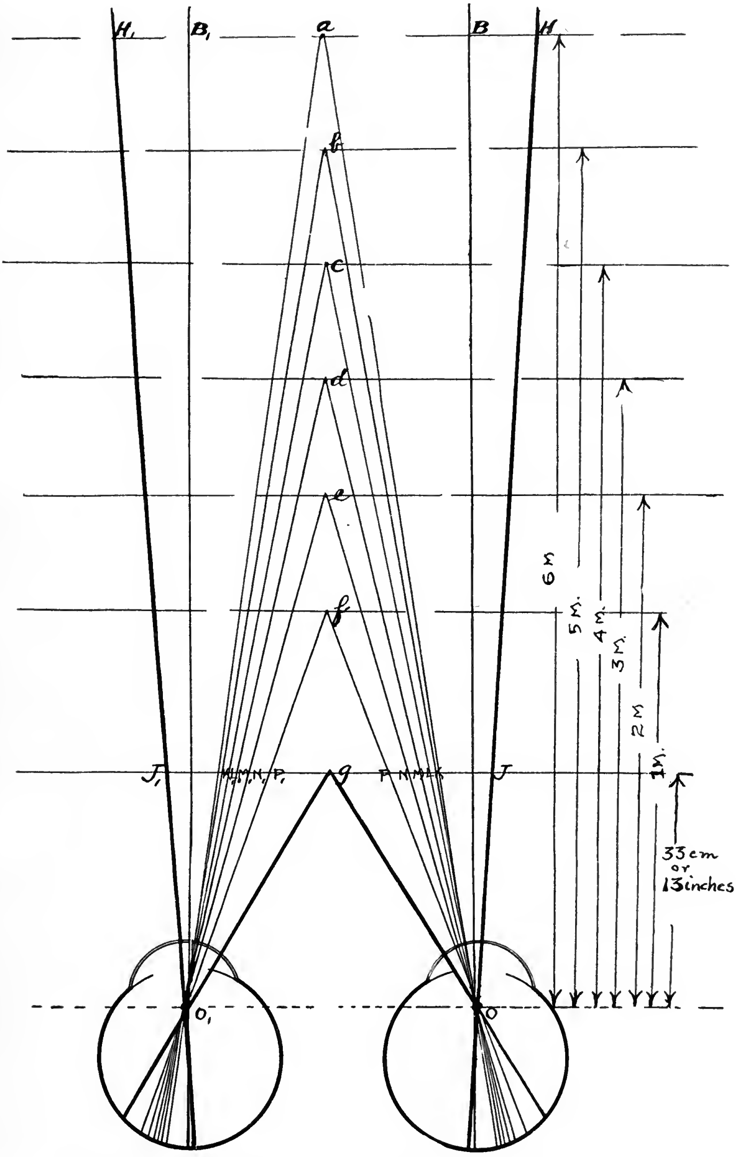


Fig. 42. Illustrating how exophoria increases at the near point

and the amount of prismatic power, *apex up* (base down), before the left eye, necessary for the line and spot to intersect is the measure of left hyperphoria present.

Why Exophoria Increases at the Near Point

As a guide to the beginner in muscle work, it is well to know that the near tests almost invariably show an increased exophoria over the distant tests. For instance, should the distant exophoria measure, say, two degrees, one may anticipate six, eight or ten and more degrees at the near point. Similarly, should the distant test show, say, one or more degrees of esophoria, the near test may show a decreased esophoria, a state of equilibrium, or a marked degree of exophoria. Figures 42 and 43 illustrate graphically the reasons for such behavior.

To elucidate the facts, let us refer to Fig. 42. Here we find a case of exophoria in which the visual axes O B and O B_1 tend to deviate to the positions O H and O H_1. At six meters distance, the exophoria present may be expressed by the angles a O H and a O_1 H_1. At five meters, the exophoria would be represented by the angles b O H and b O_1 H_1; at four meters, by the angles c O H and c O_1 H_1 and so on, until at the near point g, would be registered the maximum exophoria represented by the angles g O H and g O_1 H_1. One will observe the difference in deviation between angles g O H and g O_1 H_1 at the near point g, and the angles a O H and a O_1 H_1 at six meters distance. Their difference, represented by angles g O a and g O_1 a is the increased exophoria at the near point.

Figure 43 assumes a case of esophoria for distance. The visual axes O B and O B_1 tend to converge to the positions O H and O H_1, so that at four meters distance there would be registered muscular equilibrium or orthophoria. At six meters, however, the convergence of the visual axes O H and O H_1 with respect to what should have been their direction of fixation, namely, O a and O_1 a, establishes

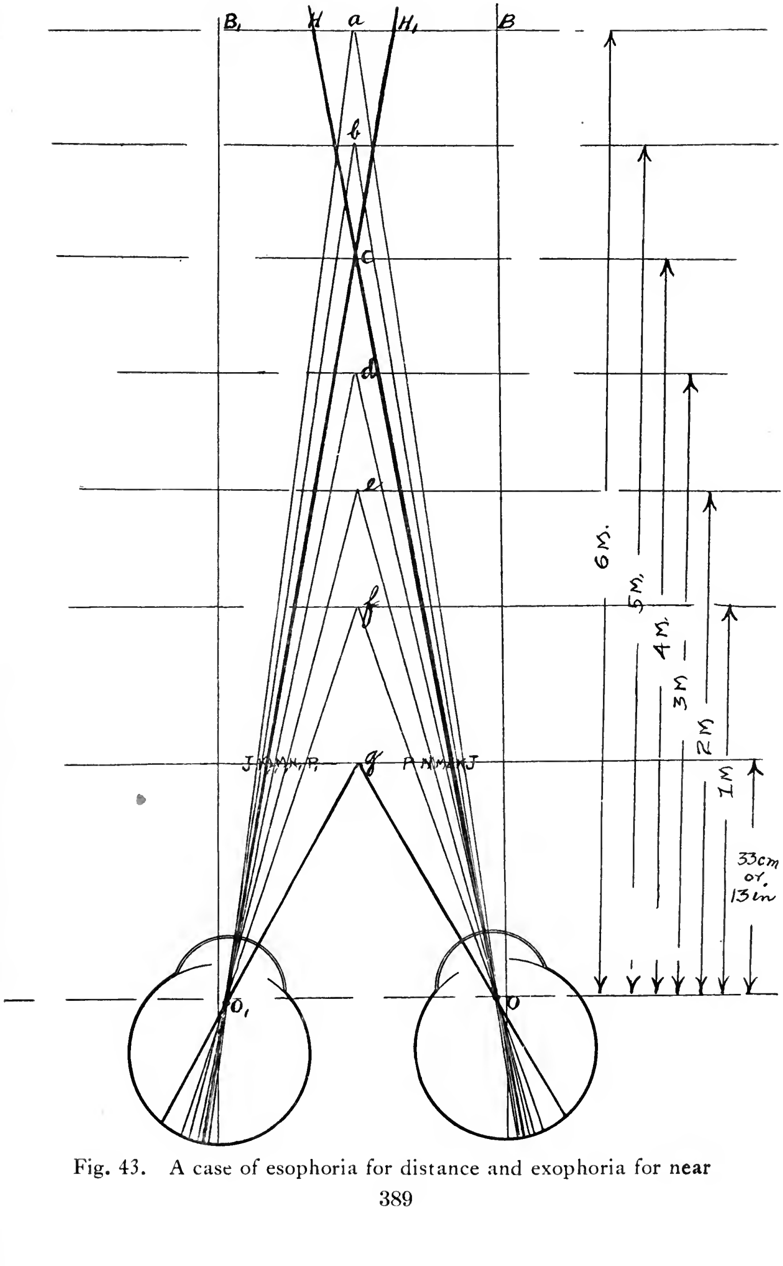


Fig. 43. A case of esophoria for distance and exophoria for near

a state of esophoria expressed by angles a O H and a O_1 H_1. Measuring at five meters distance, the esophoria is reduced, being represented by angles b O H and b O_1 H_1. At four meters distance, the inclination of the visual axes and the direction of fixation coincide and the esophoria is neutralized to the point of equilibrium. Inside of four meters and up to the reading distance, increasing exophoria, as represented by the angles d O H, e O H, f O H and g O H, continues unhampered, until its maximum is reached at the point g. This should clearly illustrate how a distant esophoria undergoes a form of absorption, so to speak, through encroaching exophoria, until at the reading distance, depending upon the extent of the distant esophoria, a reduced esophoria, a state of muscular equilibrium, or exophoria may be anticipated. Similarly, when the distant imbalance is exophoria, a substantially increased exophoria at the reading distance may be likewise anticipated. Those who have had contrary experiences have undoubtedly observed that such exceptions are rare, and are attributable to special and irregular causes.

Phoenix, Arizona

[To be continued]

Some Important Physical and Physiological Relationships between Radiant Energy and the Visual Apparatus and Processes

being

The Fourth Thomas Young Oration

Charles Sheard, Ph. D.

Introduction

THAT which man does lives after him. Man has in the past erected—and still continues so to erect—monuments of stone, builded by hand with great labor, and the sweat of many brows, to serve as memorials evidencing his existence. Man throughout all ages has left us vestiges of his presence and his accomplishments; from the creation day to the present hour men have left memorials, some tangible and some intangible, to be mute but eloquent reminders of the living, inward progress achieved. So our men and women of science have dreamed dreams and have had visions; they have, by their labors, all unknowingly and unconsciously, erected temples to the glory of God as embodied in his master creation, Man, and have built monuments to the perpetuation of the truth. But these *memorials* have not been of stone—earthy and of the "dust to dust returneth," but rather have they been the products of their own minds—spirit and personality, genius and skill. These men and women have not only bequeathed the work of their hands and the products of their inner selves to succeeding generations but they have also endowed those who have followed them with the spirit that actuated them. They have, by their lives and their works, perpetuated to us the true spirit of science—the Search for the Truth, which now we know but in part, for we but "see through a glass, darkly."

We have gathered here on this occasion to pay tribute to the name of Thomas Young and to breathe our appreciation of the love of and search for the truth which dominated this great man who lived in this great land over a century ago. True it is that Thomas Young was born an Englishman and died an Englishman. But the true scientist, while he is a member of a state, belongs to no state but rather to the world at large. For at heart the scientist—the searcher after truth and the instrument whereby the unknown may be made known—is desirous of contributing to the happiness and welfare of man some fragments which may prove good and which may become a part of the ultimate, sum total of all knowledge, to the end that man may become master of the unseen forces about him. Hence, though Thomas Young was born an Englishman, through his contributions to his fellowmen and to succeeding generations, he became one of the world's greatest scientists and one of her first citizens. It is fit and proper that the *world* should pay tribute to the name and memory of Thomas Young. For as Dr. Tscherning said in his delivery of the first Thomas Young Oration a decade and a half ago:—"It is surprising that Young played the rôle of the first man in so many different branches of science. For if you take Young as the first man in the question of the theory of light, the name of the second man is Fresnel; in the question of the anomalies of refraction of the human eye, the name of the second man is Donders; in the question of colour sense, you can call the second man Clerk Maxwell, or Helmholtz; in the question of hieroglyphics the name of the second man is Champollion; in the question of terrestrial radiant heat the name of the second man is Wells, and I have not yet finished the list. For his own reputation it would certainly have been better if Young had completely developed but one of his ideas. But for the advancement of science it was better that he did as he did. For if the second man is not frequently met with, the first one is extremely rare."

The nineteenth century will ever be famous for the working out of the great generalizations underlying both biological and physical sciences. This vast enlargement of the boundaries of human knowledge during the past one hundred years has made it impossible for one to be first except in a very limited field. No longer will it be possible for one to say, as did Young, that during his last visit to Paris he went to the Institute one Monday and had great pleasure in hearing the members of the Academy of Science discussing some theories of optics based on his own investigations and that he went there on another day and heard the Academy of Inscriptions discussing some of his hieroglyphical discoveries, and "although it did not happen, it might very well have happened that he should have heard a discussion on his theory of life assurance in the Academy of Political Science, or a discussion of his theory of music in the Academie des Beaux Arts, or even a discussion about his studies on the heart and the arteries in the Academy of Medicine. I think that the world has never seen anything like that."

But we turn from the man to his work, for of this I would speak chiefly to you, outlining some of his foundation work and the superstructure reared upon this foundation in the field of physiologic optics. No less a brilliant mind than that of Tscherning was pleased to name Young as the "founder" of physiological optics. But to your present speaker he is more than the "founder"— he is the "father" and we as his followers, by reason of the spirit which possesses us, truly feel as though we were his children, as we search farther into the fields and look adown the vistas which he first pointed out and opened to our view. We shall, therefore, in that which follows, point out some of the simple but fundamental truths in physiological optics as disclosed by Young and elaborate somewhat upon the physical and physiological relationships between radiant energy and the visual processes.

Chromatic Aberration

First of all, let us briefly consider various researches for determining the exact nature of the image received by the human retina. Is it not true that, to be technically satisfactory, and to give an exact reproduction of both form and color, paintings must be similar to the image received by the human retina? And is it not probable that the future will see the development of photographic lenses which will involve the important characteristics of the human eye such that, when used in connection with the three-color process or some further development along this line, there may be a substantial reproduction of the retinal picture? For the vast preponderance of the visual world is, at any moment, represented in consciousness by ill-defined and physically inaccurate images. Hence, it would be well-nigh insolent to assume their uselessness. Rather must they be regarded as the necessary background through which the foveal image acquires a significance it could not otherwise possess. Sensations from the periphery of the retina, with all their obscurity of form and texture, must form an essential fund of knowledge. And what are these fundamental characteristics, or imperfections, if such you desire to call them? I am sure that you will agree that they may be included under the expressions: spherical aberration, chromatic aberration, oblique astigmatism and distortion.

The eye is not an achromatic combination although in everyday life the chromatic aberration is not noticeable as such. A very simple experiment showing that it does possess this aberration consists in throwing, by means of a projective lantern, reading matter or pictures made up of different colors, upon a distant screen, and noticing whether or not different colored letters or objects appear to lie in the same plane. To nearly every observer there appears to be a noticeable depth difference. Young made the first estimates upon the chromatic aberration of the eye,

while Fraunhofer made the first reliable measurements on the difference in the focal length of the eye for extreme spectral colors. He observed a prismatic spectrum through an achromatic telescope, the eyepiece of which carried a cross-hair. Fraunhofer noticed that he had to move the ocular nearer the cross-hairs for clear vision when observing the violet region in contradistinction to the red region. Young estimated the chromatic aberration to be 1.3 D., Fraunhofer found it to be 1.5 to 3 D. and Helmholtz gave 1.8 D. One method of determining quantitatively the axial chromatism of a lens is to find the difference in inclination of rays of varying wavelength which come to the same focus. In 1914 Nutting reported his investigations on the matter of the chromatic aberration of the eye in the *Proceedings of the Royal Society*. The results obtained indicate that the human eye approaches very closely in its chromatic aberration to an eye of distilled water. Taking the refractive indices of water for red (C) and for violet (G) and applying methods for calculating reduced eyes we find a chromatic aberration of 0.434 mm. which corresponds to practically 1.1 D. In Nutting's work the results on several observers showing the relationship between relative focal distances or the axial focal lengths of the eyes and different wavelengths of light, indicated a considerable flattening through the central portion, *i.e.*, on both sides of the D line, and the assumption was made that this is due to the eyes being more or less corrected. A similar curve for water shows no such flattening but rather a convexity toward the axis of wavelength. Ames and Proctor, working at Dartmouth College, have this year published results upon the spherical and chromatic aberration of the eye. By a very much more elaborate and exacting set-up of apparatus—which it has been the pleasure and good fortune of the writer to see and examine—they have determined the axial chromatic aberration and failed to find any flattening of the focal length—wavelength curve as

found by Nutting, the suggestion being made that the flattening found by Nutting was due to his using a chromatic, *i.e.*, white light, accommodation object. Hence Ames and Proctor used monochromatic fixation; in general λ 6560. They found for the amount of axial chromatic aberration between λ 6563 and λ 4861 values varying from 0.72 D. to 0.98 D. The determination of the axial chromatism of different zones is still another problem best considered in conjunction with variations of spherical aberration with wavelength and zone of the eye examined.

Spherical Aberration·

Let us pass on to consider spherical aberration—a spreading of rays along the axis near the image plane due to different zones of the lens not having the same focal length. The great savant, Young, prepared a series of experiments which conclusively prove that the eye is not aplanatic. For a myopic eye, or one which is mechanically made so by the addition of convex lens power, sees a distant luminous point as a circle of diffusion with its lightness concentrated at the center if the eye has positive spherical aberration; if the aberration is overcorrected or if the luminous point is inside of the farpoint, the peripheral regions will be more luminous. Young gives us the experiment of passing a needle in front of the eye made myopic during the performance of this test, when the shadow of the needle will be seen in the circle of the diffusion. If the shadow remains straight at all points, there is then no appreciable or perceptible aberration; if it is concave toward the periphery ordinary aberration is indicated but if it is concave toward the center, there is evidence of an overcorrected aberration. Furthermore, Young said that such experiments showed that the aberration is not always the same in different meridians.

And then too, we have the optometer of Thomas Young—of which Tscherning says:—"It appears to me to be one

of the most important instruments for the study of physiologic optics." This instrument enables us to measure spherical aberration directly. The instrument consists of a little rule carrying a fine white line on a black background. The observer looks along this line through a +10 D. lens. In front of the lens is placed a ruler free to move and carrying small slits differently spaced so that various zones of the eyes may be examined. These slits act like the openings in Scheiner's method of testing a lens. Young determined the difference between the far points of the central portion of the eye and the peripheral parts through the use of four slits properly placed, obtaining the aberration as the difference between the two readings just cited. We shall pass over with a mere mention such classic work as the aberroscope of Tscherning, the researches of Stadfeldt and the retinoscopic methods of investigating spherical aberration, and come to the latest work of Ames and Proctor who have used an elaborate and exact means of passing a beam of light of very small cross-section through different zones of the eye and determining the inclination of the beams when their image coincided with the image formed by the axial ray. These experimenters found that the relationship between zone distance from the axis and the calculated distances behind or in front of the retina where incident parallel rays cut the axis in any instance and for each of the three wavelengths, red (6560), yellow (5890) and blue (4860), is, roughly speaking, of the form of a parabola with the axis line of the curve lying at about 1.5 mm. from the visual axis of the eye. And, generally speaking, their results indicate that for wavelengths of 5890 or greater the light is focussed by the different zones in front of the retina, while for the shorter wavelengths it is focussed behind. Furthermore, these investigators have examined the spherical aberration with different wavelengths of monochromatic illumination in both horizontal and vertical meridians. The result showing the spherical aberration

of different zones with different wavelengths of light indicate that the aberration curves are practically independent of wavelengths used, that the forms of the curves for horizontal and vertical meridians are practically the same, but that there is for each and every wavelength a difference between the focussing point of horizontal and vertical meridians. They found, for instance, in the case of one observer, that this difference of horizontal and vertical meridian image focus amounts to about 8/100 of a millimeter for λ 6563, λ 5893 and λ 4861. There is also the much mooted question as to whether the eye so focusses as to allow that part of the cone of light which has the smallest diameter to fall upon the retina or rather that portion where the section of the caustic due to spherical aberration is smallest. Tscherning and Gullstrand believe it to be that portion of the bundle where the caustic is the smallest and not where the cone has the least diameter. Ames and Proctor believe that they can definitely assert that, in the eyes examined, they focus on that portion of the bundle where the cone has the least diameter.

Oblique Astigmatism

For a long time oblique astigmatism has been known to exist in the human eye and was first dealt with in a fairly comprehensive manner by Young. Such an astigmia causes the rays of light from a point source not on the axis to focus into a ray bundle of quite complex character. In its pure form in a simple lens, a ray bundle from a point source focusses first to a line which lies in a tangential position to a circle about the axis of the lens; it then crosses with a narrowing in its long dimension and lengthens in the short one until it again becomes a line perpendicular to the first line, or forms what we speak of as the radial line. The farther the source from the axis of the line the greater the separation between the two parts of the image which have the forms of lines. Young, in 1801, remarked on the small

extent of perfect vision. Imperfections which begin a degree or two from the axis are due, he claimed, in part to the aberration of oblique rays and again to the insensibility of the retina. He calculated the positions of the primary and secondary astigmatic image fields of a circle ten inches from the eye. He gave curves showing first and second astigmatic image fields formed by the cornea only, by the cornea and anterior surface of the lens, and finally by the cornea and the whole lens. From the time of Young on, we find three methods employed in the endeavor to determine the position of the primary and secondary astigmatic fields:—(1) ophthalmoscopic—Stammerhaus, Schoen, Rimpler and Staub; (2) skiascopic—Parent and Drualt, and (3) subjective determination of position of sharp focus of paraxial stimuli—Peschel, Albini, Wertheim, Heinrich and Loria. In a general way, the results obtained by different experimental methods agree that the image of oblique rays formed by the dioptric system of the eye is astigmatic; that the retina lies approximately half-way between the primary and secondary image-fields formed by a surface in space, all points of which are equidistant from the eye, and that monocular space perception is tridimensional. Ames and Proctor, in the work already referred to, have endeavored to make accurate determinations of the position of the astigmatic fields for light of different wavelength. The curves for different wavelengths show a marked similarity but the form of the curve for the primary differs considerably from that of the secondary astigmatic field. Corresponding to the different colored image fields there are, of course, object views in space. These can be accurately determined for any given accommodation of the eye. For example, the nature of the image of a white light point source situated two meters away being considered, it is found that the red light will be stretched in a tangential direction, the yellow light in a radial direction, and, being beyond the second astigmatic field for green and blue, these colors

will be in the form of a radial diffusion circle. Hence, the two very important conclusions:—(1) With any given accommodation, every object in space has its characteristic retinal image form due to its position in space relative to the fixation point and (2), this characteristic image form is governed both by the shape and color of the object. Thus the notion of uniocular tridimensional space perception, first recognized as a possibility by Heinrich, is given a very definite basis. And again, it follows that, with any given accommodation, the nature of the images on the retina from stimuli of different wavelength all at the same distance from the eye would be very different both in shape and intensity, hence it is possible that past measurements on peripheral color sensitivity may be somewhat invalidated. And thus we see, by way of a general conclusion at this point, the importance of researches for determining the exact nature of the image received by the human eye, with reference to which the initial investigations were carried out by Thomas Young, and in addition we see the intimate relationships existing between such experimentation and the technic of the art of actually reproducing that which the eye views.

Astigmatism

In the mind of the clinician and those interested in the applications of physiological optics to the care of the human eye, the name of Thomas Young will doubtless always be associated with the discovery of astigmatism, published in the *Philosophical Transactions* for 1793. First of all, Young proved the defect in his own eye by means of his optometer and by observing the forms of the circles of diffusion produced by a luminous point. We know that he had an astigmia of about 1.7 D. against the rule. Furthermore, he proved that his astigmatism was not located in the cornea because, by performing the very celebrated experiment of putting the eye under water and substituting a

spherical lens for the cornea, he found that the astigmatism persisted and to the same amount. In 1827 the astronomer Airy corrected his defective sight by means of cylindrical lenses. From that day to this there have been many methods and instruments devised for the detection of the amount and the axis of the astigmatism of the eye. The ophthalmometer is accredited in matters of discovery to von Helmholtz and was made a valuable clinical instrument by Javal and Schioetz. Helmholtz introduced into ophthalmometry the principle of doubling; it seems, however, that the method had already been used for the same purpose by Thomas Young—again showing the versatility of the mind of this genius.

An eye which has an insufficient resolving power shows, in general, three defects:—(1) A marked loss of power to sustain the adjustments needed for clear seeing, (2) an undue lag in making the adjustment necessary for clear seeing and (3) the fact of increased amount of light required to first discriminate details in the standard acuity object. In the past we have quite commonly pursued methods of examination of ocular defects involving changes in visual angle rather than illumination. But, in so far as the test object is concerned, clearness of seeing depends upon both the visual angle subtended and the illumination. Hence either the visual angle scale or the illumination scale may be used for the detection of the defects of the eye considered as an optical system, *i.e.*, the visual angle may be varied and the illumination kept constant, or the converse. The illumination scale, however, possesses the greater sensibility for the detection of small errors, and from recent experimentation we are satisfied that visual radiant energy, *i.e.*, illumination, constitutes the superior method in detecting the exact amount—and, in the case of astigmia, the placement of the correcting cylinder—of visual interference which exists because of physical defects of the eye as an instrument. For if the eye has an equal resolving

power in all meridians, the amount of light required to just discriminate a test object in all meridians will be the same; if the resolving power is not equal, the amount of light will be different in the various meridians and different by an amount proportional to the amplification represented by the illumination scale. In particular is this true in the determination of the amount and the exact placement of the correction in cases of low astigmatisms. Clinical methods as ordinarily pursued may vary easily in conclusions from 0.12 to 0.25 D. in strength of cylinders and, in the case of low astigmatism, from 5 to 20 degrees in the placement of the cylinder axis. These inaccuracies may affect keen acuity, speed in the use of the eye, speed of discrimination and in the adjustments of the eye for clear seeing at different distances. And the resolving power is of importance in expressing the difference in the amount of light that is required by different people as a working minimum and is of particular significance in explanations of acuity in twilight conditions and doubtless also in "night-blindness," so called. Experimental tests made by several—and these results have been largely verifications of the work of Ferree and Rand—show the superiority of the illumination scale for the detection of the exact amount and placement of the cylindrical corrections. To indicate the sensitiveness of this method let us cite a condition in which, with +0.12 cyl. ax. 55°, it was found that equal illumination was required for the discrimination of the test object in all meridians. Clinical methods, as ordinarily pursued, gave +0.25 cyl. ax. 70°. The difference in the amount of light required for the discrimination of the test object in the least favorable meridian for the two corrections was 0.39 m.c. or approximately 244 per cent. From a study of these illumination scale methods and from a first-hand acquaintance we feel that greater accuracy will be forthcoming in the future in the detection and correction of errors of refraction, and especially in the application of

illumination methods to astigmatism, the error of the eye first discovered and measured by Thomas Young approximately a century and a quarter ago.

Mechanism and Seat of Accommodation

The second great merit in physiological optics attributable to Thomas Young is the first definite proof that accommodation is due to an increase of convexity of the crystalline lens. Young's paper on *The Mechanism of the Eye*, published in 1801, was written especially to support this contention. He eliminated possible corneal curvature changes during accommodation by observing that during this act there was no change in corneal images, but that an easily visible change could be produced by exerting a pressure on a peripheral portion of the cornea. This change of curvature was considerably less than that which would be necessary to explain accommodation. And Young added further to the evidence on this subject by performing his classic experiment of "putting the eye under water." This he did by taking the objective of a microscope which had as nearly as possible the same refractive power as the cornea, filling the tube with water and placing it in front of his eye, also submerged in water. The dioptric effect of the cornea was thus eliminated and was replaced by the unchangeable objective. In this experiment the amplitude of accommodation (about 10 diopters for Young) was preserved, showing that it was not a function of the cornea. Young found that accommodation is not produced by an elongation of the globe. By use of his optometer he demonstrated that persons operated on for cataract lost their accommodative power. He thus firmly established his belief that this power resides in the crystalline lens and hence that it could result only from a change in its curvature. To be sure, Young incorrectly supposed that the changes in the shape of the lens was caused by the character of the lens fibres. The manner in which the changes were

produced in curvature of the crystalline lens remained unknown for a half century after Young and until the work of Bowman and of Bruecke.

It is of interest to us to note that the experiments of Home and Ramsden caused Young to abandon his initial conception of the *modus operandi* of accommodation. Home and Ramsden conceived of the act of accommodation as being due to a change in the length of the eye as well as in the curvature of the cornea. That which apparently caused Young to lose faith in his own notions was the statement that the eye of a man in which the lens had been couched was still susceptible of this adjustment. As we have said, he was led to re-assert his theory of lenticular action by reason of his experiment of putting the eye under water and of discovering that several young subjects operated on for cataract had completely lost the power of accommodation. But, while rare, there are a considerable number of cases on record of the ability of an aphakic eye to read small print with the same glass as is used to see clearly at distance. Three or four such cases have been officially reported in America within the past year. Various causes may be operative to explain this phenomenon; Jackson in an editorial in the *American Journal of Ophthalmology* for April 1921 cites and discusses eight possibilities. But in none of the cases reported has there been any data recorded, in so far as we know, of actual observations made as to the mechanism of the altered adjustments of the aphakic eye reading through distance corrections. It is possible that considerable very valuable information will accrue from such observations.

Young also made observations which, as he said, amounted to a mathematical demonstration of his solution of the seat of the accommodative changes, these observations showing that the accommodation is much stronger in the center of the pupil than near the margin; a circumstance which he believed proved that the surfaces of the lens

flatten near the margin at the same time as the curvature increases in the center. We are all aware of the very elaborate and exhaustive experiments which corroborated and extended the early work of Young and which were carried out by none other than the greatest of living physiological opticists, Tscherning. True it is that we have the two rival theories of Helmholtz and Tscherning with numerous adherents to both theories. We may, as we pass on to other topics, well pause long enough to wish that we may be fortunate enough to possess in our day and age a complete and irrefutable theory of the mechanism of accommodation. Possibly we already possess it and fail in our ability to apply it in all particulars.

Color Vision

We turn from a consideration of some of the physical relationships between radiant energy and the eye as a physical instrument, and in which Thomas Young played so important a part as the original investigator thereof, to the presentation of some of the physiological and physical relationships between radiant energy and the visual processes. We have immediately before us such important problems as those of explaining the phenomenon of vision, of deciphering the enigma of color vision, and of settling the question as to whether it is the character of the radiant energy or the quantity of the same which may produce marked retinal changes under extreme conditions and which may be one of the primal, if not the primary, cause of definite changes in the structure of the ocular media, especially the crystalline lens. Far be it from me to presume to definitely answer any of these most important and as yet unsolved problems in the field of physiological optics. But we may with great propriety discuss color vision, for Thomas Young gave the world the first reasonably satisfactory theory of color vision which, as modified by Helmholtz and bearing the name of the Young-Helmholtz theroy, has

received the approval of many scientific minds. And it is indeed fitting to discuss in this oration the nature of the visual process or processes, for we may well believe that Thomas Young, were he living today, would endeavor to fathom the actual mechanism of vision, which would include not only processes occurring in the eye but also those which are located in the optic nerve and the brain centers to which the conductors of this nerve lead. For I think we may rest assured that the *retinal* factors in the process have been over-emphasized, for the visual consciousness must depend fundamentally upon central nervous processes and only indirectly upon those of the retina. For we must needs consider the correlation of the retinal factors with the essential nervous system. Due to the excellent work of Lucas, Adrian, Nernst and others on the physical basis of nerve excitation, including much information as to the nature of the nerve fibres and synaptic activities, we are now possessed of knowledge of nerve functions. And the investigations of Sherrington, Head and others throw a great deal of light on the nature of the synaptic or nerve processes.

Young Theory

There are extant some sixty or more theories of the mechanism of the visual response. Three have proven sufficiently valuable to be discussed in textbooks on physics, physiology and psychology. These three are those of Young (and Helmholtz), Hering and Ladd-Franklin. All of these theories postulate the existence in the retina of a number of specific chemical substances which are acted upon by light. There are, according to the theory of Young, three of these substances which are decomposed at maximal rates by red, green and blue (violet) light respectively. These decompositions are reported to the brain along the path of the optic nerve. Young laid down the premise that white light is composed of a mixture of three colors

only, namely, red, green and violet, and postulated the existence of nerve fibres in the retina composed of these sub-members or fibres, each provided with a special terminal organ. Helmholtz modified this hypothesis by assuming that each spectral color irritated all these fibres at once but in a different degree. Koenig, Maxwell, Abney and others, by studying the color sensations of normal eyes as well as of color-blind persons, have drawn three curves showing the sensitiveness of the assumedly three primary sets of nerves to stimulation by light of different wave lengths. The theory of Young serves to explain many facts of color vision, but it appears to fail completely to explain the radical changes in the character of the colors which are experienced when certain ratios of the elementary processes are realized: for example, the combination of red and green to form yellow or of yellow and blue to form white. And the phenomena of after-images are only approximately reconcilable with this theory and the problem of simultaneous contrast is not satisfactorily explained. However, the three color curves receive independent verification along different lines, notably from the distribution of hue sensibility in the spectrum, which coincides with the resultant of the slopes of the chromatic curves at any wavelength, and again from the facts of pure chromatic minuthesis, serving to identify the intersection points of the curves.

The recent work of Allen, resulting in conclusions in support of the Young theory, is particularly impressive. In Allen's experimentation, a long series of persistency curves was made under the following conditions: A certain color in an arc light spectrum was isolated and the eye kept constantly fatigued with it. With the retina in this condition, persistency measurements were made throughout the second spectrum. The persistency curves thus obtained were compared with those obtained with an eye in a normal condition. By means of his work, Allen believes that he

has established the fundamental red sensation as lying between the red and the point of transition at 6600A. Similarly the fundamental green sensation is excited by some portion of the spectrum lying between the second and third transition points at wavelengths 5700A and 4700A. And the third fundamental sensation, which he says must be violet and not blue, lies between the fourth point of transition at 4200A and the end of the violet. Proceeding through the spectrum, we pass from the fundamental red, through the transition point at 6600A to compound sensations (yellow), through the transition point 5700A to the fundamental green sensation, through the transition 4700A to compound sensations (blue), and through the transition point 4200A to the fundamental violet sensation.

Barton and Browning have investigated mathematically and with the aid of models the probable mechanism of the Young-Helmholtz theory. Three resonators of appropriate natural vibration periods were subjected to forced vibrations. Photography was employed to record their respective amplitudes of response; the natural periods corresponded to 7600, 5500 and 4000A. Mathematical analysis showed that the vibrations must be very highly damped in order to produce the resonance curves required by the facts of color vision. The damping demanded is so great, however, that persistence of vision cannot be explained as a result of the continued action of the vibrations after cessation of the stimulus. The ratios of the responses of the three systems of vibrators to different impressed frequencies were found to experimentally fit in very well with many facts of color vision: such, for example, as the mixing of various monochromatic portions of spectral energy.

Hering Theory

The theory of Hering also postulates the existence of

three substances: one of these substances is decomposed by lights of all wavelengths, although to the greatest extent by yellow-green light. It builds itself up in the absence of light. The other two substances are decomposed at a maximal rate by red and yellow lights respectively and are recomposed at maximal rates by green and blue lights respectively. The six psychological primary colors are correlated with the six different and distinct rates of change occurring in the three substances. We have here a satisfactory explanation of the manner in which these primaries combine with one another, accounting for the antagonistic behavior of red and green, and yellow and blue. Negative and complementary after-image effects are also explained and the facts of color vision doubtless as satisfactorily presented as in the Young-Helmholtz theory. Verworn and others have criticized the Hering theory in the matter of the assumption that anabolic processes can be brought about by the direct action of a stimulus. Grave objections to the Hering theory lie in the failure of opposite processes in the black-white substance to cancel each other, while those in the other two substances always leave a residual gray, and the fact that psychologically primary red and green do not combine to give a gray but instead a yellow. And last of all we should mention the failure of continuous stimulation of a single retinal region to reduce the effects (sensory) of all stimuli to a neutral mid-gray. The first difficulty has been discussed by Mueller, who differentiates between retinal and brain center processes, placing the substances postulated by Hering in the retina and assuming the existence of an additional gray-producing process in the centers. The third difficulty mentioned would seem to be overcome only by giving up the cardinal feature of the Hering theory, *i.e.*, the antagonistic natures of the processes involved in the three pairs of primary colors. Some few years ago Troland propounded a theory obviating this difficulty, in which he suggested five distinct

light-sensitive substances in the retina, each acted upon by light, the rate of decomposition being at a maximum at different wavelengths for the different substances. One substance was responsible for white light and the other four for red, yellow, green and blue respectively. Blue is represented as an unstimulated condition of the visual brain center.

Ladd-Franklin Theory

The Ladd-Franklin theory is possibly the most satisfactory of all the classical theories, as many call them, in that its basic points are probably essential to a satisfactory elucidation of the visual process. In her theory a single light-sensitive substance assumedly exists in the retina. This substance exists in three stages of differentiation. In the first stage its decomposition leads to various gradations of achromatic luminosity ranging from black, in which there is an absence of stimulus, to white, in which there is a maximal rate of decomposition. In the second stage of change of substance we find postulated two parts, one of which is decomposed at the maximal rate by yellow light and the second part by blue light, the products of these decompositions respectively acting upon or being transmitted by the optic nerve to produce yellow or blue, as the case may be, in consciousness. Simultaneous and equivalent decomposition of the two parts of the substance again gives the original or first stage of stimulation and thereby gives a gray. The third stage of decomposition or change of substance consists in the breaking up of the yellow-sensitive component into red and green-sensitive constituents respectively. We see, therefore, that red and green are antagonists, as in the Hering theory, but the product is yellow instead of white. The yellow, coming into antagonism with blue, gives us the quality of white or gray.

But there are two distinct mechanisms of response in

the retina; the cones—dominant in day vision and giving both achromatic and chromatic sensations, and the rods—giving responses to low illumination or furnishing twilight vision and giving only achromatic sensations. We feel that this *duplicity theory*, which has to do with the differentiation of functions only, is reasonably well established. All things considered, it seems that the Ladd-Franklin theory—accounting for the psycho-physical response of the retinal cones and taking into account the three-color mixture laws upon which the Young-Helmholtz theory is based—supplemented by the assumption of an independent rod response for twilight vision, constitutes one of the best working (if not the best) hypothesis we possess of what we may call the retinal processes in contradistinction to that which may occur from the retina back to and including the brain centers.

Coördination of Retinal and Cortical Functions

The more primitive the theory of vision the more certain is the visual consciousness considered as being determined by the object. The most advanced ideas or conceptions look upon the visual projection areas of the cerebral cortex as of prime importance. The facts of pathology clearly indicate that we are justified in postulating in the cerebrum the existence of highly elaborated and differentiated visual mechanisms and processes. There is apparently a special cerebral responding center for every distinct feature of the optic function. And pathological changes in the visual areas of the cerebral cortex are capable of causing pronounced changes in color vision without any equivalent effect upon other visual function. We do not, for instance, need any assumption of retinal contrast mechanism, because the function of contrast can remain operative when lesions in the projection areas have practically annulled intercourse between the higher cerebral areas and the retina. Modi-

fications in color vision due to pathological conditions in the visual cortex indicate the existence of definite cortical processes corresponding to the constituents of the visual consciousness.

In all three of the prominent theories—Young, Hering and Ladd-Franklin—there is the temptation, at least, to correlate the cerebral reactions with individual nerve centers; thus demanding a red-perceiving center, for example, as the recipient of red retinal process product. Recent investigations rather lean toward the conclusion that specific qualities of sensation depend more upon characteristic nerve processes than upon anatomic centers. In nerve physiology we know that certain reflexes antagonize and inhibit each other; it is apparent that such a mutual inhibition exists between the cerebral components for red and green respectively. But this antagonism which inhibits both red and green, for instance, does not kill out the energies involved but generates the yellow component. And in a similar fashion yellow and blue inhibit each other but thereby produce the sensation of white.

Certainly the scheming out of a probable cerebral mechanism of color vision is an herculean task. From the retina to the cortical area, we may conceive of receiving stations for the various functions. The basic functions are those of brightness, form and color. Disorders in the calcarine region of the occipital cortex attack the color function first of all, then the perception of form and finally the recognition of brightness. It is likely that the chromatic function is centered in one of the higher strata of the cortical mechanism. Should we proceed backwards from the cortical area ultimately involved toward the retina, we may well pause to ask how the several factors in the visual processes are represented in the nerve at different neural levels. The arguments in support of the Young-Helmholtz theory indicate that, between the cortical region concerned and the retina, the nerve conduction must involve three

independent variables. Helmholtz assumed that there were three different kinds of nerve fibres and receptors in the retino–neural mechanism. Others, equally philosophical, have postulated a threefold qualitative differentiation of the nerve currents passing along a single nerve fibre. This latter hypothesis seems, from recent experimentation, to be more difficult of acceptance than at the time of its conception. For, from the researches of Adrian and Lucas and the demonstration of the so-called "all or none" principle for the response of nerve tissue, we find that an impulse which passes along a nerve fibre is incapable of *quantitative* variation, being fixed in magnitude by the properties of the fibre. The number of nerve fibres in simultaneous action would afford gradation in muscular activity. Or the basis of gradation might be the frequency of the impulses, *i.e.* whether they are densely or sparsely distributed. In visual sensations we can hardly explain variations in intensity or luminosity on the number of fibres in action, since the number of fibres presumably explains the variation in the area of retina stimulated. Evidently, then, it is possible to explain variations in intensity of stimulation of the retina by means of the conception of nerve impulse-frequency. Recently Troland, employing a well-known entoptic phenomenon first described by Purkinje, has measured the brightness of the effect produced by the stimulation of certain retinal receptors by the nerve currents generated in the conducting fibres of the retina as a result of stimulation of other receptors, and has found that this brightness is independent of the intensity of the stimulus which is initially applied to the retina. Apparently the frequency is the only factor which can explain luminosity variations. If this is true, then theories of vision based on the analogy of the telephone cannot be accepted, since variations in amplitude of the nerve pulses to transmit the intensity cannot be admitted to be true according to the "all or none" principle. And further, the telephone idea

of visual response cannot be admitted because of the fact that a telephonic representation of a light wave in a nerve current should be composed of waves whose lengths are smaller than the diameter of an electron. If the visual currents are actually quantal in character, they must have frequency and this frequency will be variable. Such a variation may easily be presumed to form a basis for the transmission to the brain of the intensity of luminosity, for brightness vision precedes form and color vision. The idea of impulse frequency as the basis of brightness vision satisfactorily explains achromatic vision, but fails to afford a basis of color perception. But hue and saturation enter in a very minor way into laws which govern luminosity, and suggest the physiological distinctness of mechanism underlying chromatic and achromatic vision. Furthermore, that luminosity and chromatic values are actually independent factors in the physiological processes fundamental to vision is indicated by the decided differences in the proportionality constants relating these two factors for different spectral colors. The luminosity may be merely a proportional accompaniment of the chromatic value of the sensation. Recent work by Ferree and Rand indicates that the periphery of the retina—in which rod vision predominates—is not blind to red, blue and yellow, for with stimuli of sufficient intensity the limits of red, blue and yellow coincide with the limits of white light vision; the limits for green seem to be absolute, however. But the amount of change of intensity required to produce a detectible change in the apparent limits of sensitivity in the more remote parts of the retina is very large. The implication that luminosity and color vision are not intimately related but are quite largely independent is evident.

If we consider the chromatic function by itself, the evidence that it depends upon three selectively sensitive mechanisms is apparently very strong. The individual cones may be trichromatic or there may be three separately

connected and distinctive species of receptors underlying color vision. Deliverances of responses of adjacent elements would undergo fusion in the brain; otherwise we should never see "white" as such but as mosaics of three colors. Recently Hartridge has demonstrated that such fusion does occur, for minute color patterns falling upon a considerable number of cones are perceived in their combined or integrated effect. If the retinal cones are differentiated into three classes, then it is possible that the "all or none" principle should hold, and that the three species of conducting fibres should differ functionally, for the individual impulses travelling along them might have different characteristic amplitudes. Troland finds that there are significant differences in the thresholds for different colors used to produce the "blue arc" effect.

And again, it is possible that phase, or phase difference, may be present in the propagations of impulses along nerve tracks of the visual mechanism. Such is true in audition; but localization in vision does not rest upon differences of phase as in the localization of sound. With a uniform luminosity, colors might be due to particular relative displacements of the phases of adjacent impulse streams. Achromatic sensation would depend upon exact synchronism of adjacent impulses, while chromatic vision would depend upon definite deviations from this condition. We can easily conceive of phase differences as being produced by differences in the exact position of the source of the impulses in the retinal layer. Experiments recorded by Koenig and Zumft indicate that the retinal layers which are sensitive to the various parts of the spectrum do not coincide. This difference in position of sensitivity might be due to the relative positions of specific responsive substances within the receptor organs or to other properties of the same. We may comment that the laminae into which the rods and cones split up transversely to their lengths are admirably adjusted to produce optical interference effects within the

receptors. But the data on the duration of the nerve pulses and its rate of propagation are large as compared with the dimensions of the rods and cones, and this throws grave doubt on such a possibility as that mentioned. But Darzens used the principle of interference in a somewhat different manner, for he supposes standing waves produced by reflection between the receptors, and that the energy nodes and loops are situated at different distances and positions for various wavelengths.

Chemical Theory of Vision

At any rate, the effect of the sensations of light in the retina is perceived by the brain as a visual sensation. The process or processes are still very obscure. Some of these we have hinted or have briefly discussed; we have said but little, however, as to the possible means whereby an ether disturbance can produce a reaction ultimately recognized by the brain as a visual sensation. Broadly speaking, we have three theories: (a) chemical, (b) mechanical and (c) electrical. According to the chemical theory, certain visual substances (or possibly substance such as the visual purple) in the retina are affected by light and vision originates from metabolic changes produced in these visual substances. The metabolic changes consist of two phases; the upward, constructive or anabolic phases, and the downward, destructive or katabolic change. The visual purple has, in general, played a most important part in chemical theories. But we know that the rate of decomposition and of rebuilding of visual purple is very slow as compared with the act of vision. Edridge-Green states his belief as to the nature of retinal stimulation as follows:—"A ray of light impinging upon the retina liberates the visual purple from the rods and a photograph is formed. The rods are concerned only with the convergence of light impulses to the brain. The ends of the cones are stimulated through the photo-chemical decomposition of the visual purple by light,

and a visual impulse is set up which is conveyed to the brain through the optic nerve fibres. The character of the stimulus and impulse differs according to the wave-length of the light causing it. In the impulse itself we have the physiological basis of light and in the quality of the impulse the physiological basis of the sensation of color."

And again, Edridge-Green assumes that the cones of the retina are insensitive to light but sensitive to the changes in the visual purple. Light falling upon the retina liberates the visual purple from the rods and it is diffused into the fovea and other parts of the rod and cone layer of the retina. The decomposition of the visual purple by light *chemically* stimulates the end of the cones—probably through the electricity which is produced—and a visual impulse is set up.

Mechanical and Electrical Theories of Vision

The mechanical theories are built in large measure upon the basis of resonance phenomena in conjunction with chemical action. It is readily conceivable that a ray of light can cause a chemical decomposition of a substance in which the rhythmic excursions of an atom or atoms from, or round about, the center of attraction in a molecule are in tune with the waves of light falling on such atoms. Likewise photographic and mechanical examples afford us illustrations of responses produced in which the periods of stimulating body and responding body approximate each other. For example, we have the sensitivity curve of silver chloride, showing a rise in sensitiveness followed by a decline as the portion of the spectrum used for stimulation is changed.

Houstoun has lately attempted another explanation of color on the basis of the visibility curve of the eye. He believes that the visibility curve is explicable on the supposition that there exists in the eye a very large number of vibrators with a free period in the green and that these execute forced vibrations under the influence of the light

waves and that the amplitude of the forced vibration is a maximum when the free period of the vibrations coincides with the period of the incident light. When the energy of the vibration reaches a critical value, the force attracting the vibrator to its center snaps; the latter then ceases to absorb light energy and a chemical change takes place. This critical period is not the same for all the vibrators but varies from vibrator to vibrator.

Houstoun's theory, either implicitly or explicitly, contained within itself sufficient to cause me in 1917 to write: "We have here, it seems to the writer, the fundamental principle of the so-called quantum theory applied to explain visual phenomena. According to this conception, energy, E, is radiated in discrete or definite units and is connected with the frequency, ν, and the universal constant h, through the equation $E = n\ h\ \nu$. The detachment of one, two, three and so forth (n) electrons will give rise to varying quantities of radiation, which are multiples of a definite energy unit." Professor Joly of Trinity College, Dublin, has this year published a couple of delightful papers containing a discussion on a quantum theory of vision.

It may properly be objected at this point that we have jumped over the traces and that we are not discussing a mechanical theory of resonance but rather that which we are about to discuss in a few moments, namely, an *electrical* theory. But we feel inclined to believe that none of the modern resonance theories, in which vibrators are concerned and in which free and forced vibrations are involved, assume or imply the assumption of the vibrators as being the rods or the cones *per se*. Nothing, at least, can probably be further from the truth, because a simple calculation shows that if any microscopically observable structure is to resonate in tune with even the longest light wave, it would need to possess a modulus of elasticity several million times greater than that of steel.

We believe that the ultimately successful doctrine as to

the mechanism of vision must involve the conception of electricity, for light is an electro-magnetic phenomenon and can react only with electrical or magnetic systems. The essential features of the photo-ionic (or photo-electric) visual process consist of the assumption that the rods and cones contain certain electrolytes or ionizable substances which in the absence of light are ionized to an extent determined by the equilibrium constant of the reversible dissociation action. The introduction of light into the substance alters the value of this constant by increasing the rate of dissociating substance. Such an action would be the result of the absorption of light energy producing an increased ionization as a volume effect in the body of the receptor cell. Or possibly the action is a truly photo-electric one, in that it is a surface effect with the ejection of electrons from the surface of the retina. In the older physics we should write of resonance as a correlation between radiant energy and the chemically dissociated atom. In the light of modern physics we should write and speak of resonance of radiant energy and electrons. In fact, the essential points in the mechanical theory of retinal stimulation as consisting of resonance effects coupled with chemical action fit in with many of the physical phenomena known as photo-electric actions. We are, therefore, presumably dealing, under the tenets presented to us in this theory, with the expulsion of electrons due to resonance; the electrons are set in resonant vibration by the incident light and acquire sufficient velocity to enable them to escape from the atom. From the viewpoint of modern science we may regard it as fairly certain that the first stage of any photo-chemical reaction consists in the separation of negative electrons under the influence of light. It is obvious that the absorption of light is necessary before any change can be brought about. According to the theory of Grotthaus we may say that the "action of a ray of light is analogous to that of a voltaic cell."

Retinal Current Responses

Hence the electrical theory supposes that the visual impulse is the concomitant of an electrical impulse; that an electrical current is generated in the retina under the influence of light and that this is transmitted to the brain. It is an undoubted fact that light gives rise to electrical retinal currents and that, on the other hand, an electrical current properly applied causes the sensation of light. Holmgren, Dewar, McKendrick, Kühne, Steiner, Waller, Gotch, Einthoven and Jolly, and Sheard and McPeek, have shown that illumination produces electric variation in a freshly excised eye. Currents of injury must be eliminated and other precautions taken to avoid spurious effects. All investigations are in agreement that the retina under illumination becomes more negative than the nerve end, which appears to indicate that the negative ions of the receptor cells diffuse more readily than do the positive ones, and this is just the reverse of the case for the nerve proper. When the retina is stimulated by light, the original potential difference is increased rather than being decreased. The action of light is to increase the negativity of the retina. This is exactly what would occur if light increased the ionization of the substance or substance inside of the cells. Or possibly the potential difference increase may be due to the ejection of electrons from atoms in the vicinity of the membrane; this action would be strictly analogous to that occurring in the photo-electric effects with metals. Careful experiments by Joly and later by Poole with the black pigment of sheep and oxen and with fresh retinas gave no results indicating a surface emission of electrons. But we seriously question whether any such surface emission should be expected. For, in the eye at least, we have presumably no accelerating potential. Rather do we conceive of the process as one in which volume ionization takes place and in which the diffusivity of negative and positive ions is sufficiently different as to develop a difference

of potential between the retina and the first neural station or synapse along the visual path.

Quite recently Sheard and McPeek have carried on investigations as to the retinal current responses to light of varying wavelength. The eye in each case was stimulated continuously with a given narrow spectral region for a period of several minutes and the relationships between time of stimulation and increase or decrease of potential difference between the stimulated retina and non-stimulated nerve-stump were obtained. Constant stimulation produced fluctuations in the nerve current of about 12 seconds period combined with a progressive change in the potential of the nerve stump with respect to the cornea, this change consisting of an increase in the positive potential of the nerve for the longer visual wavelengths and a decrease for shorter wavelengths lying roughly at 5300 Angstroms. There is evidence, therefore, of two processes operating in the producton of retinal electric potentials and that, in general, the cold colors stimulate the production of negative potentials (from retina to nerve) while the warm colors produce positive potentials. Results were obtained showing that practically no retinal potential changes occur, after the neutral period of excitation by light of a particular spectral character, unless exposures are made in a region very closely approximating the complementary color and that when so exposed, the potential is carried back approximately to the value which it possessed prior to the dual exposure. Hence, when a given potential level has been established under a certain spectral stimulant, the complementary in turn produces the maximum deviation from this level.

In a general way, therefore, the experimentation on the retinal (electric) currents set up in enucleated eyes under light stimulation indicates:

1 That positive retinal currents are manifested and positive electromotive forces established when an eye is illuminated by light.

2 That the source of these electrical changes lies in the retinal structure or in the posterior part of the eyeball.

3 That luminous stimuli of different wavelengths—from red to violet—give initially positive retinal currents. Hence all responses are of the same general type, and act in accordance with their luminosity.

4 That the stimulus-response relation is such that the curve representing it is concave to the axis representing the stimulus.

5 That fatigue is less pronounced in the case of the retina than in that of muscle.

6 That the time-relations of the responses or periods of latency after application of stimuli are of the order of 2/10 to 1/2 a second.

7 That there is a characteristic response to darkness as well as to light stimulation.

8 That the range of light vibrations under which animals' (frogs quite largely) eyeballs give definite photo-electric responses corresponds very closely to the range of vision of our own color sensations.

9 That photo-electric effects with sensitive cells may be obtained which are wholly analogous to phenomena obtained with eyeballs.

10 That experimental results point to the localization of two photo-electrical substances in the posterior half of the eye-ball or that the retina is the seat of a double electrical movement which may consist of duplex changes in one substance or of two changes in two different components or substances.

With respect to this last conclusion as to the presence of two photo-electric substances or of duplex changes in one substance, we have the very recent work of Selig Hecht on the photo-chemistry of visual purple and human retinal adaptation. The course of retinal dark adaptation, he concludes, is a bimolecular one; two substances are decreasing in concentration according to the ordinary velocities

of chemical reactions. The substance synthesized during dark adaptation is the photo-sensitive substance and the two materials which form this photosensitive substance are its precursors as well as its decomposition products. The initial process in visual reception in dim light must, therefore, depend on a reversible photochemical reaction in which a photosensitive substance is broken down into two decomposition products. During dark adaptation of the retina these two decomposition products then unite to form again the sensitive substance which gave rise to them.

These retinal currents have their counterparts or analogues in non-organic substances when exposed to light. Sensitive inorganic cells may be constructed; for example, we may take a hollow cup of silver and sensitize the inside with bromine vapor, fill the cup with water and roughly imitate the eye in composition and in having a sensitive receiver and a less sensitive conducting nerve-stump. Such a cup, under alternate exposure to light and freedom therefrom, shows a series of response and recovery curves, the counterpart in every wise of the responses and recovery of the retinal currents in frogs' eyes. In general it may be said that the responses of the retina to the stimulus of light are in every way similar to those of certain sensitive inorganic cells. In both we have, under normal conditions, a positive variation; in both the intensity of response, up to a certain limit, increases with the duration of illumination; it is affected in both alike by temperature; in both there is low fatigue effect; the increase of response with intensity of stimulus is small in both; and furthermore, even in deviations from normal responses, such as reversal of response, preliminary negative twitch on commencement, and terminal positive excess on cessation of illumination, and decline and reversal under continued action of light, parallel effects are found.

The action of luminous stimulation upon the retina must

lie without doubt in the ionization processes set up in the visual receptor cells. What these processes are or what the nature of the changes produced is still an enigma. However, ionization involves a dissociation into positively and negatively charged atoms and electrons. A stimulation by light must, therefore, set up a certain process of ionization whereby the positive ions may be thought of as moving in general in one direction and the negative atoms (if such exist) and electrons as moving in opposite directions. Photo-electric activities of metals, such as sodium, show a discharge of negative electrons under the action of light, the rate of discharge depending upon the metal and the character of the illumination. However, we need not think of motion of both sets of ions but of one only, for example, the electrons, and that membranes and tissues are more permeable to one than to the other of the ionized products. We may suppose that substances in the absence of light are ionized to a degree dependent upon the equilibrium constant of the reversible dissociation action. The introduction of light into the system alters the value of this constant by increasing the rate of the dissociating change without affecting that of reassociation. It seems not improbable, therefore, that the passage of one set of charged particles out of the receptor cells along nerve trunks will thereby increase the potential difference between retina and nerve and cause a building up of a surplus of the second kind or set of charged products of the ionization process which, by accumulation, will inhibit and in large measure sweep out the oppositely charged products of dissociation when the concentration becomes sufficient.

Using these facts and others Troland has evolved a theory of visual impulse as consisting of the actual propagation of the positive ion, I_+, from the rod and cone cells along the optic nerve and tract to the cerebellum and that the propagation takes place with the speed of the visual impulse. The propagation occurs within neuro-

fibres which are thought of as *molecular tubes* within which it is possible for ions to travel without encountering great resistance. And Troland leads us through to his conclusion as to the general nature of visual cerebrosis from this account of the mechanism of the impulse and postulates that "the cerebral state corresponding with any condition of retinal stimulation consists simply in the presence in the cerebral cells of the specific ions (or electrons) which are liberated in the retina by the action of the light."

And H. S. Allen had evidently in mind somewhat the same notions in his communication to the Roentgen Society in 1919. For he believes that it is unnecessary to assume that a photo-chemical change is the cause of the visual sensation; it is, he says, "sufficient to suppose that photo-electric action takes place in the chemical substance or substances, contained in the rods or cones, so that we have a separation of electrons resulting in electrification of the nerve cells which set up the nervous impulse to the sensorium. If this view is correct, the changes in the retina are identical with those which take place in a phosphorescent substance or with those which take place in the formation of a latent image on the photographic plate." And the fact that the form of the curve which shows the relation between the sensitiveness of the retina to light of different wavelengths bears a very close resemblance to the curve which shows the variation of photo-electric activity with wavelength, is also in support of this contention. But, on the other hand, Coblentz, of the Bureau of Standards, concludes that, in his opinion, evidence is not sufficient to warrant the belief that there is a connection between the phenomena of color perception and brightness and the phenomena of photo-electric sensitivity of inanimate material, and that, considered as a whole, spectro-photo-electric sensitivity in solids is only vaguely, if at all, similar to visual response.

Quantum Theory of Vision

We may, therefore, in conclusion—being of the firm

belief that the visual receptor process is of a character included within the broad term photo-electric—review some points with reference to the (quantum) theory of vision as presented recently by Professor Joly. The fundamental assumption is, very naturally, that the origin of brightness and color visions is to be sought in the liberation of electrons from a photo-sensitive substance or substances. The rhodopsin is such a substance. Furthermore, the spectral range of vision is in excellent agreement with the spectral absorption curve of the visual purple, and this is to my mind one of the most enticing evidences that rhodopsin plays a very important part in some manner in vision. It may simply form the intermediary or catalyzer between light and the nerve.

And again, the rods contain the sensitizer in the form of rhodopsin. The electrons set free by light action expend their kinetic energy in stimulating the nerve and doubtless establish an electromic current into the ganglion cell or synapse with which the nerve makes connection. If the rods very completely absorb light energy, there will be a free and copious development of electrons; a confused flow of stimuli to the nerve—some with low and some with maximum kinetic energy—will follow, too mixed and too crowded to permit of analysis. The sensitivity of rod vision is indeed extraordinary. Henri and de Bancels have shown that the retina is sensitive to an amount of light energy of the value of 5×10^{-12} erg. The quantum for green light is practically this figure. We may believe, therefore, that one quantum is sufficient to excite vison: that is saying that the liberation of a single electron by green or blue light can excite visual sensation. It is easily shown that in viewing a standard candle at the distance of 3000 meters some five to ten electrons are liberated in each rod per second. There is of course absorption of energy which may be expended in other ways than the ejection of electrons. But it is evident that a few electrons (at least

one) must be conserved so as to make their way to the optic nerve. Hence the stimulus arising from one quantum must constitute an appreciable portion of the threshold stimulus.

The cones are structurally different in that they contain no visible quantity of visual purple. Doubtless the outer segment of the cone is bathed in a photo-sensitive fluid—probably rhodopsin. Here the light is absorbed; either at the surface of the cone or within the thin layer separating cone from cone. Some electrons produced by light stimulation do not escape from the sensitizer. The fastest, however, carry into the nerve the full quantum of energy which is characteristic of the frequency giving rise to them. If the intensity of the light is considerable there would be many of these electrons which would be the most effective in exciting a nerve stimulus. Color vision is in abeyance at very low luminosities; this may be explained on the basis that there are insufficient of what we may call "characteristic" electrons to excite color sensation. And again, when color is excited, there will always be a dilution of white because of the presence of the slower-moving electrons and "non-characteristic" of the frequency which gives rise to them. Hence quantitative sensitivity may be assigned to the rods and qualitative sensitivity to the cones. In one case the sensitizer is located within the nerve and in the other is located outside of the nerve. "The sensory stimulus emanating from the rods is compounded of many sources of stimuli, *i.e.* such as may originate in electrons possessing every velocity and kinetic energy up to the maximum proper to the frequency of the activating light. The stimulus emanating from the cones, on the other hand, is purified of all stimuli save those arising from the kinetic energy of electrons which are activated by the energy of absorbed quanta. The electrons are, in fact, selectively presented to the nerve; all other sources of stimuli take place outside the cone and are cut off from it by the filament

which invests it. In the cone the more intense stimuli tap out to the brain the sensation of color which we associate with the intensity of the quantum involved. To this succession of characteristic nerve impulses there is added an underlying accompaniment; the white or luminous sensation made up of all the feebler electrons which impart to the nerve but a fraction of that which is characteristic of the frequency of the light entering from the world without." (Joly, *Phil. Mag.* Feb. 1921.)

And as we draw this oration to a close we feel that the enigma of vision is still awaiting solution. Unfortunately the science of physiological optics, in so far as it deals with the correlation of the acts of visual consciousness with material factors and processes, has not reached the stage of development comparable with its sister science, physical optics. For our theories of vision are so frail and so puny as compared with the exactness of the mathematical sciences. Such must, perhaps, always be the lot and fortune of that which deals with the animate in contradistinction to the inanimate. All the more necessity, therefore, for bringing to the solutions of such problems the trainings of the physicist, the physiologist and the psychologist. For it must be all too obvious to us all that the explanation of the phenomena of vision in their entirety must involve a knowledge of the laws of the brain and its operation, the functions and structure of nerve tissues, and the physical chemistry of the retinal processes. We plead for a closer coördination of these sciences and we hope that the future will be the possessor of investigators of wide acquaintance with these fields, so that the theories of the physicist, for instance, may not, as they are propounded to explain phenomena involving animate material—flesh and blood and all that these tissues include—be of no avail because of their failure to take into consideration physiological and psychological facts. We may not hope for many— if any— geniuses of the future so fortunate as to embody the full

complement of all that we have asked for, since such an enormous expansion of knowledge has taken place since the time of Young, but we can hope for a closer coördination and association in experimental work to the end that kindred minds may work together, each presenting a different viewpoint and each serving as a stimulus and a check at the same time.

Thomas Young was one of the intellectual giants of the scientific world, for his work shows us his wonderful insight into physical laws and phenomena, his wide acquaintance with the principles of medicine and physical diagnosis as then developed is portrayed in his "*Practical and Historical Treatise on Consumptive Diseases*," and his knowledge of the workings of the human mind is portrayed in his writings on insanity, pioneer efforts as we now know them to be. These are but evidences of a catholicity which is unique. We of average ability are constrained to concentrate our attention to very narrow regions of investigation, but this limitation enables us to all the more admire and look with wonder upon that master mind, able, with power and profit to his own and succeeding generations, to range over the whole wide field of human knowledge. So may we continue to reverence the memory of Thomas Young by being "doers as well as hearers of the word."

Abstracts and Reviews

The Prevalence of Lenticular Opacities in the Eyes of Tinplate Millmen

James J. Healy

Nature of the Work

EACH mill has a personnel of four men; respectively, the furnaceman or heater, the doubler, the rollerman and the catcher. Steel bars are heated red-hot in a coal fire furnace. These are rolled out, then returned to the furnace to be heated red-hot and the process continued until the proper thickness is obtained. The heat is very great; the ordinary furnace would be unable to stand it for longer than a few minutes. (The writer says his "hands and face were scorched at the end of such an experience.") The men first enter the mill at about 18 years of age and at the end of two or three years become furnacemen. All men in the mill are exposed to infra-red rays from the red-hot tin plates. The furnacemen and doublers are, in addition, exposed to the infra-red rays given off by the furnace; the quantity of ultraviolet rays is negligible. During the manipulation of the red-hot tinplate the distance from the workman's eyes varies from two to five feet.

Results of Investigations

The writer found that about 40 per cent of men of 35 years of age and over had lenticular opacities of various types. Two types of opacity predominated: (1) the round dense posterior cortical and (2) the striated cortical wedge-shaped opacity, apex upwards, growing in the lower cortex.

An investigation was made at the suggestion of the Iron and Steel Trades Confederation. Some 424 men were ex-

amined in addition to 96 cases in private practice. Of the 424 men examined, 70 were under the age of 35 years and only one case of lenticular opacity was found. In his later visits the writer examined only those of 35 or more years. Out of 354 men of 35 years of age and over, 144 were found to have lenticular opacities, or practically 40 per cent. The age distribution is given in the following table:

Age	34-40	41-45	46-50	51-55	56-60	61 & over
Number of men examined	74	67	65	61	53	29
Number of men found to be suffering from lenticular opacities	13	12	22	38	34	20
Percentage of ditto ditto	17.5%	18%	34%	62%	64%	69%

The writer's impression is that a man does not develop a lenticular opacity before he has been at work in the mill fifteen years.

Two tables are presented which cover 209 cases and give data as to (a) age, (b) occupation, (c) number of years in work and (d) remarks on character of the opacities found in each individual case. "We find that the typical wedge-shaped striated cortical opacity below, with its apex upwards and growing in to the posterior cortex, predominates and occurs alone in 105 cases. Dense round posterior cortical opacity, similar to that supposed to be typical of bottle-maker's cataract, occurred in 26 cases. The two above mentioned types were found associated in 20 cases. Nuclear opacity alone was found in 4 cases. Dense posterior cortical opacity associated with nuclear opacity was found in 2 cases. In one case, it was possible to differentiate dense posterior cortical, nuclear, cortical striae below as well as anterior cortical and capsular opacities. In 31 cases the cataract had been extracted or was so advanced that it was impossible to say what the initial type was. In 13 cases the types were miscellaneous, and in 7 cases the

opacities were complicated by other disease. The types were evenly distributed over the various ages. In 112 cases where the hand forward on the tongs was recorded, the eye first affected corresponded to the hand forward. In 17 cases the converse obtained.

Incipient Types

Can a definite type or types of incipient opacity be established as being common among tinplate millmen or as being in any way pathognomonic of what we may now call Tinplate Millmen's Cataract?

"Since attention was first drawn to the prevalence of cataract amongst bottlemakers in this country by the publication by Robinson in 1903 of Dalgleish's and his own experiences in the Sunderland Eye Informary, most observers have described the posterior cortical type as being pathognomonic, notwithstanding the fact that they all in their notes of cases recorded the existence of other incipient types, either existing alone or in combination with the posterior cortical type. It is possible that too much attention has been focussed upon this type and that observers have not given the consideration they might have to other types. Robinson in his description of the typical incipient posterior cortical opacity describes it as being irregularly disc-shaped in outline and of cob-webby texture. I have seen a few cases of this nature amongst tinplate workers, but the majority of the incipient posterior corticals I have seen have appeared by transmitted light as distinctly black dots, or at a later stage round or irregularly round black discs which are almost always central, so that my experience agrees more with Legge, who describes the opacity as being like a blot of ink. This type of opacity is not confined to bottlemakers and tinplate workers, but is occasionally to be seen in old people as a senile type. I have seen two or three cases in women. It cannot, therefore, be regarded as the preserve of the bottlemakers and

the tinplate millmen. My own records of tinplate millmen and the records of observers of the bottlemakers' cataract show that the posterior cortical type often exists in combination with cortical striae and presumably the cause (whether it be ultra-violet rays or heat rays) of the one is also the cause of the other.

"There is another type of incipient cataract which I have found more common in tinplate millmen than the posterior cortical variety, and that is a broom-like opacity in the lower cortex, with the striae very crowded together until at the base they form often a conglomerate mass. This opacity is usually wedge-shaped with apex upwards, and it grows as a rule in the posterior cortex towards the posterior pole, and occasionally into the anterior cortex. The base is either directly downwards, or downwards and inwards, and the striae rarely spread externally. The apex is often very blunt or rounded. This form rarely spreads externally and above until the lower half of the lens is well involved. This opacity is seen occasionally amongst cases of senile cataract, but not nearly so frequently found in combination with the posterior cortical type, and my own feeling is that in tinplate millmen, at any rate, we have two pathognomonic types."

Aetiological and Pathological Theories

"The majority of ophthalmologists in this country regarded the infra-red rays as being the probable cause in the production of bottlemakers' cataract. More recently experiments have been carried out in America by Burge and others who seek to place the blame at the door of the ultra-violet rays. These experiments have been done mainly *in vitro* or upon frogs and fish. The nature of the experiments was that of acute, rather than chronic, exposure to concentrated ultra-violet rays in no way comparable to the conditions under which trade cataracts are supposed to be produced. Although interesting, they help us

very little in the aetiology of the diseases under review. It has always been advanced against the heat rays' theory that there was no record of cataract amongst workers in the iron industries who were exposed to red-hot iron and steel and this was the weak link in the chain of evidence. I think that the statistics which I have given above, if they can be borne out by others, will supply a fresh and very strong link in that chain. In the tinplate mill the men are exposed to practically no ultra-violet rays, but they are exposed constantly to excessive amounts of infra-red rays.

"Hartridge and Hill have shown that the iris absorbs practically all the infra-red rays between λ5,000 and λ13,000 and that radiations of greater wave-length are absorbed by the cornea and aqueous. The curve for the lens shows absorption to the extent of 10 per cent to 30 per cent of the heat rays between λ11,000 and λ13,500. We do not know exactly in what manner the heat radiations cause cataracts, and I plead this as an excuse for advancing certain possibilities which might form a basis of research. It is reasonable to assume that the lens itself in a tinplate millman is constantly absorbing considerable quantities of infra-red rays, and that these cause acceleration of its metabolism, probably an over-rapid growth of the lens fibres at first, and finally exhaustion of this process at the time when it is most necessary, namely, when sclerosis and shrinking of the nucleus begins. It is probable also that the lower portion of the eye receives more direct rays owing to the position of the head (bent forward slightly) and the screwing together of the lids. This would result in shading of the upper and outer part of the cornea and expose the inner and lower portion. Possibly, however, the most potent factor in the probable production of cataract by heat rays is the enormous absorption by the aqueous, the iris, and ciliary body. Here the enemy is attacking the headquarters of the eye's physiological life. The intestine and kidney of the eye, so to speak, are subject to chronic irritation

which must result in an alteration in the secretory endothelium, in the secretions entering the eye, and in the selective mechanism of the excretory endothelium. The eye might now be likened to a man with an impaired digestion and a granular kidney, and it is probable that excess of salts, proteins, and end products of the eye's metabolism are retained. The lens depends upon the ciliary body through the vitreous, the aqueous, and the suspensory ligament with Petit's canal for its nourishment, which takes place mainly by diosmosis it is supposed; if this be the case the increase in the dissolved constituents of the aqueous would materially alter the normal metabolism of the lens. The nature of this alteration is obscure, but it is probable that degenerative changes occur more quickly in the innermost fibres which shrink and lose their nucleus, and the lens being of epithelial origin they become cornified and form the outer layers of the nucleus. By this time the growing epithelial cells have been overworked and cannot keep pace with the demand for production of new fibres to fill up the space produced by the shrinking of the older fibres, and fissures occur between the fibres of the cortex. These fissures become filled by fluid, and secondary degeneration occurs in the fibres surrounding. It is just possible that some of the heat absorbed by the iris and ciliary body, especially in the lower part, may be conducted along the zonule and the aqueous of the posterior chamber to the lens capsule, and may so damage the epithelial layer as to allow filtration through it of minute amounts of aqueous. Fuchs states that slight filtration occurs through the endothelium on the posterior corneal surface when it is the seat of inflammation or deposition of inflammatory products. This would account, therefore, for the opacity starting in some cases in the lower segment of the lens. The nutrition of the vitreous, being dependent on the ciliary body, no doubt also suffers. It is probably subject to sclerosis of its limiting membrane and trabeculae,

and possibly to a slight shrinking in volume. The limiting membrane of the vitreous is firmly attached to the posterior pole. We have now two bodies on either side of the posterior pole of the lens, each with a tendency to almost imperceptible shrinking. It might be possible for a slight detachment of the posterior capsule of the lens to occur at the posterior pole, and for fluid to collect beneath the capsule. Next to the equator, the greatest shrinking of the lens would occur at this point, and in the cases where the posterior cortical variety occurs I would advance this series of events as a possible cause. This does not exhaust all the possibilities. We have no exact knowledge of the lymph channels of the vitreous; the existence of a lymph channel in the position of the embryological hyaloid vessel is debated, but should it exist, it is not improbable that it forms a further channel of communication for exchange of nourishment and waste products between the lens and ciliary body *via* the vitreous. Research along these lines might throw some light on the production of the posterior cortical opacity.

(Abstracted from *The British Journal of Ophthalmology*, Vol. V, pages 194-210, 1921.)

Sensitivity of Illumination Scale for Determining Exact Amount and Placement of Correction for Astigmatism

C. E. Ferree, Ph.D., and G. Rand, Ph.D.

An eye which suffers from an insufficient resolving power shows the following functional defects:—(1) An undue lag or slowness in making the adjustments needed for clear seeing. (2) A marked loss of power to sustain the adjustments needed for clear seeing. (3) An increase in the amount of light required to just discriminate details in the standard acuity object. This last is considered in this paper.

The relation of the illumination scale to the detection of small errors of refraction may be briefly stated as follows: In so far as the test object is concerned, clearness of seeing depends upon the value of the visual image subtended and the illumination. Hence either the visual angle scale or the illumination scale may be used for the detection of errors in refraction, *i. e.*, the visual angle may be varied and the illumination kept constant or the converse. The illumination scale possesses the greater sensitivity for the detection of small errors of refraction, and when used in this way the illumination scale becomes in effect an amplifying scale. In clinical cases it has been of particular value in determining the exact amount and placement of the astigmatic correction.

"That is, if the eye has equal resolving power in all meridians, the amount of light required just to discriminate the test object in all meridians will be the same; if the resolving power is not equal, the amount of light required will be different in the different meridians and different by an amount proportional to the amplification represented by the illumination scale. This gain in sensitivity over the clinic methods is needed in particular to determine the exact amount of the correction in case of high astigmatisms and both the amount and exact placement of the correction in case of low astigmatisms."

Clinical methods give corrections which may be and frequently are off from 0.12 to 0.25 diopter in strength of cylinders and, in case of low astigmatism, from 5 to 20 degrees in the placement of the cylinder axis. These inaccuracies may affect keen acuity, especially at low illuminations; the power to sustain acuity; speed in the use of the eye, especially speed of discrimination, and of making the adjustments needed for clear seeing at different distances. In fact, experience shows that the resolving power is very important in explaining the difference in the amount of light that is required by different people as a working minimum.

Tests show that an illumination-range from 1 to 9 meter-candles produces an increase of something like 75 per cent; hence this range is quite feasible and the relation between the two scales (visual angle and illumination) gives abundant sensitivity. Results show that in the majority of cases the minimum of light required for the discrimination of the opening in the broken circle (visual angle 1 minute at 6 meters) in the most favorable meridian was of the order of 1 to 3 meter-candles and in the least favorable meridian, of the order of 6 to 9 meter-candles.

The following types of material were used:—(1) Artificial astigmatisms made through the use of cylinders of low diopter value: this is probably not equivalent to natural astigmatism, as the natural astigmatic eye may progressively acquire power to compensate in part for its defect. (2) Natural astigmatisms without a cycloplegic. (3) Office and clinic cases with cycloplegics, in which it is concluded that the difference between a true and false correction has been thus far of a considerably greater order of magnitude with than without a cycloplegic. (4) Office cases submitted by skilled refractionists for checking purposes. (5) Irregular astigmatisms.

The following case illustrates the method:—

"Case I. (age 13 years.) R. Correction by clinic methods, +0.25 cyl., ax. 70°. (Placement of axis could be varied over a range of about 45° and cylinder could be changed to 0.12 diopter without noticeable change in the results by these methods.) With this correction illumination required with opening of circle in meridian of cylinder axis, 0.20 m.c.; at 90 degrees from this position, 0.55 m.c.; difference, 0.35 m.c. or 175 per cent.

Correction by illumination method, +0.12 cyl., ax. 55°. With this correction equal illumination (0.16 m.c.) was required for the discrimination of the test object in all meridians.

Difference in amount of light required for discrimination

of test object in least favorable meridian for the two corrections, 0.39 m.c. or 244 per cent.

L. Correction by clinic methods, +0.12 cyl., ax. 180°. (Placement of axis could be varied over a range of about 45 degrees without change in result by these methods.) With this correction illumination required with opening of circle in meridian of cylinder axis, 0.12 m.c.; at 90 degrees from this position, 0.21 m.c.; difference 0.09 m.c. or 75 per cent.

Correction by illumination method, +0.12 cyl. ax. 15°. With this correction equal illumination (0.105 m.c.) was required for discrimination of test object in all meridians.

Difference in amount of light required for discrimination of test object in least favorable meridian for the two corrections, 0.105 m.c. or 100 per cent.

The writers discuss various methods of procedures for correctly determining the amount of astigmatism and the position of the correction cylinder. The following are particularly pertinent in modern practice:

"A quicker and more feasible method, however, is first to make an approximate determination of the amount and placement of the correction by the clinic methods and employ the illumination scale only for a more precise determination. In using this method as a refinement on the clinic methods, the procedure we ordinarily employ is as follows: The patient's eye is fitted with the strength and placement of cylinder indicated by the clinic tests; and the minimum amount of light required to discriminate the opening in the circle is determined in four positions, two in the meridian of the cylinder axis and two in the meridian at right angles to this. If the minima are not equal in these four positions, the cylinder is shifted and the determinations are made again in the four positions, the opening of the circle always being in the meridian of the cylinder axis and the meridian at 90 degrees from it. As a precautionary measure other positions may also be tried. If no placement

of the cylinder is found which gives equal minima for the four positions, the strength of the cylinder is changed. The strength and placement of cylinder which require both equal and the smallest amounts of light for the four positions of the test object are accepted as the final correction.

"The apparatus can also be used to advantage with astigmatic charts of the sunburst type, the radial lines of which are no more than 5 degrees apart, in the preliminary approximate determination of the axis of the defect. In this case the procedure is to reduce the illumination until only one or perhaps two of the lines stand out clearly. This would give a sensitivity roughly speaking of about 5 degrees, and requires little more time than is usually consumed in the use of the astigmatic charts."

The writers, in conclusion, point out the value of the illumination method as a check in practical refraction work —and that without doubt the method has its chief value in those cases in which it is particularly difficult to make a decision by the ordinary clinical methods.

(Abstracted from *American Journal of Ophthalmology*. Vol. 4, page 22, 1921.)

Microscopy of the Living Eye with the Slit Lamp of Gullstrand

Robert von der Heydt, M. D.

AFTER discussing the introduction of the slit lamp of Gullstrand in 1911—which has apparently opened up an entirely new field and method of diagnosis—mentioning the work of Koeppe of Halle and Vogt of Basel, and describing the combination of slit lamp and corneal microscope by Prof. Henker of Carl Zeiss, the writer describes some of his own observations.

In diaphanoscopy the tissues are transilluminated by reflection of true light from a surface beyond the object

under observation. These reflections of light from limiting surfaces are often seen when using the ordinary ophthalmoscope, and in particular the reflection from the anterior corneal surface is an annoyance. With the slit lamp method of Gullstrand, however, these assume decided usefulness, for a microscope can be focussed upon them and a world of information as to the structure of the limiting surfaces obtained. Koeppe uses a contact glass applied to the eye, thus eliminating corneal refraction, and in this way the retina may be studied under a magnification as high as 70 times.

Among the observations of the writer are the following:

(1) The limbus presents a whorl of vascular loops and arcades, with their convexity toward the cornea. The greater part of these vessels are normally empty.

(2) Below the cornea there is in many persons a series of straight tubular structures which Vogt calls "palisades" and which represent the superficial pathway to the vascular loops at the limbus.

(3) At the corneal border a physiologic dew-like infiltration of the cornea may be noted.

(4) Schieck describes in serous iridocyclitis small glassy bodies which form masses like frog-eggs or they may be as delicate as spiderwebs in their appearance. This sticky material interferes with the outflow of the aqueous through the pectinate ligament into Schlemm's canal, hence the tendency to secondary glaucoma.

(5) One of the most beautiful phenomena I have seen with the slit lamp is the process of dilatation and contraction of the pupil under low power. The rounded edge of the pupillary border is rolled in and out somewhat as when a curtain is wound over a pole During dilatation for instance, posterior areas appear from behind the pupil, and roll forward onto the iris, on account of the contraction of the superficial muscles. The stroma is most artistic in its balcony and latticelike formation when seen in the perspective.

(6) Senile cataract manifests itself in its incipiency by an iridescence of the layer directly under the capsule. Senile changes are not sub-capsular but involve the whole of the cortex. In most cases the nucleus remains comparatively clear, so that apparently mature cataracts may be opaque only in the cortical substance.

(7) Most beautiful are the remnants of the embryonic vessels on the posterior lens capsule. If properly focused they may be seen in every human eye. Also in conjunction with this it is noted that the attachment of the hyaloid artery is not in the lens center but somewhat nasal and downward, corresponding anatomically in that respect to the displacement of the entrance of the optic nerve on the back of the eyeball.

(8) The vitreous has a definite supporting structure.

(9) By the use of the contact glass of Koeppe the fundus can be seen stereomicroscopically and magnified about 40 times. The crossing of the retinal vessels one above the other is beautifully seen. In cases of retinitis pigmentosa Koeppe has ascertained that the pigment may wander into the vitreous.

(Abstracted from *American Journal of Ophthalmology* Vol. 4, p. 171, 1921.)

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I

III

The American Journal of Physiological Optics

A QUARTERLY JOURNAL

Edited by

CHARLES SHEARD, PH. D.

VOLUME IV

1923

Published by the Division of Ocular Interests

American Optical Company

Entered as second-class matter January 20, 1922, at the post office at Southbridge, Mass., under the Act of Congress of March 3, 1879

I

American Journal of Physiological Optics

Volume IV, 1923

INDEX

D

E

F

G

H

I

J

K

L

M

V

W

The American Journal *of* Physiological Optics

Aberrations of the Eye*

A. Ames, Jr., and C. A. Proctor

ORDINARILY the expression "aberrations of the eye" suggests the common defects of the refractive system which are encountered by the ophthalmologist and refractionist. They are myopia and hypermetropia and corneal astigmatism.

Properly the expression includes not only the above mentioned defects but all the aberrations of the lens system of the eye, as spherical aberration, chromatic aberration, oblique astigmatism, or astigmatism of incidence, the chromatic error of magnification, coma, and distortion. It is some of these latter less well known characteristics of the image formation that will be dealt with.

SPHERICAL ABERRATION

Spherical aberration is a spreading of rays along the axis of vision near the retina due to different zones of the lens system of the eye not having the same focal length. This is shown in Figure 1. If a screen A with two little holes in it at (a) and (a′) is put before the unaccommodated eye a ray of light from a point source at infinity coming through the opening (a) would cut the axis o o′ at (b) while the ray coming through the opening (a′) which would cut it at (b′).

* It is the purpose of this paper to give in a more comprehensive form the information in a paper published in the *Journal of the Optical Society of America*, Vol. V, No. 1, January 1921, pages 22-84. Those desiring more detailed information as to measurements of the apparatus and methods of adjusting are referred to that article.

This is due to the fact that the outer and inner zones of the lens system refract rays through different angles. As a result two images of the point source at infinity are formed on the retina, one at c and the other at c′. It is evident that if the screen A was removed the image formed by the entire aperture of the lens would be spread over a larger area than if the eye did not have spherical aberration. That is, spherical aberration prevents the formation of perfect images and thus affects visual acuity.

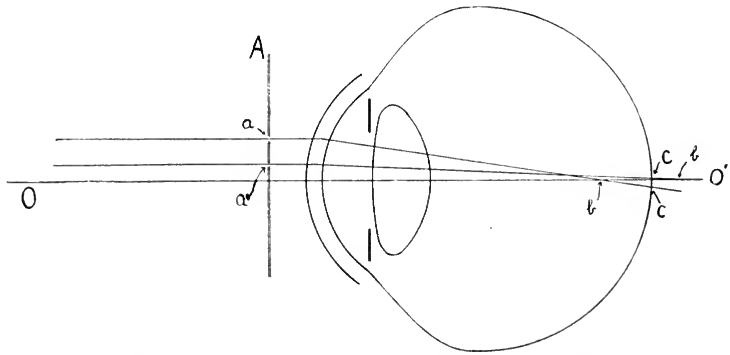

Fig. 1. Illustrating the phenomenon of spherical aberration due to different zones of the lens system not having the same focal length.

A very good summary of the work that has been done on the determination of spherical aberration in the human eye is given in Tscherning's *Physiologic Optic*, which has been translated into English. Gullstrand, in the last edition of Helmholtz *Physiologischen Optik*, also deals with the matter at some length. Various methods, which are described in the above references, have been used to determine the amount of spherical aberration in the eye. It was the purpose of our research to obtain more exact quantitative results than had been gotten heretofore.

Described in general terms, the method used was to pass beams of light of small cross-section through different zones

of the eye and determine the inclination of these beams when their images coincided with the image formed by an axial ray.

This can be explained more clearly by referring to Figure 2, which represents an eye accommodated on a point source of monochromatic light situated at infinity. A screen A is put in front of the eye with a small opening at (a′) which lets a ray of light from the point source fall along the axis

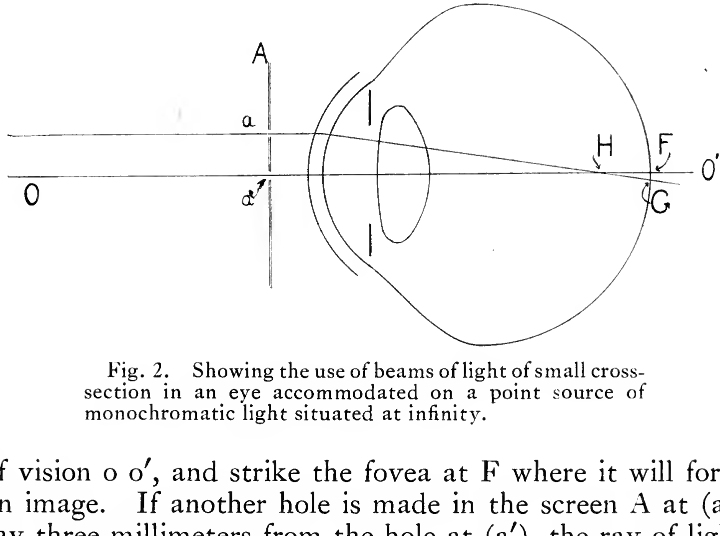

Fig. 2. Showing the use of beams of light of small cross-section in an eye accommodated on a point source of monochromatic light situated at infinity.

of vision o o′, and strike the fovea at F where it will form an image. If another hole is made in the screen A at (a), say three millimeters from the hole at (a′), the ray of light passing through it will also pass through a zone of the lens system of the eye which is approximately three millimeters from the axis. Due to spherical aberration this ray crosses the axial ray o o′ at H and is imaged on the retina at G, and the eye sees two images. If now the inclination of the ray passing through (a) is changed the image at G can be made to coincide with the image at F. The amount of this change in inclination being known it is very easy to calculate the distance H F which gives us the spherical aberration for that particular zone. The distance of the

opening (a) from the opening (a′) is then changed and the spherical aberration for another zone is determined in a similar way.

In order to obtain an axial ray of fixed direction and a

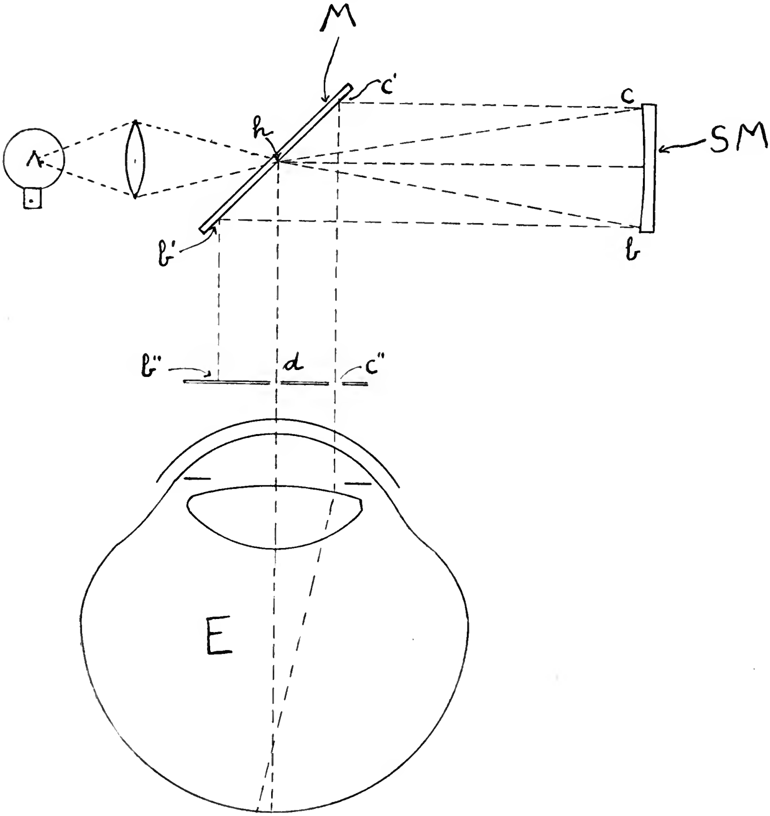

Fig. 3. Showing how the experimental ensemble produced an axial ray of fixed direction and a ray whose inclination could be varied.

ray whose inclination could be varied a set-up embodying the general principles as shown in Figure 3 was used. It consisted of a point light source at (h) made by focusing

the filament of an incandescent light on a small hole in (M) a mirror placed at an angle of 45° with the axis of the light beam. The light from h strikes upon a spherical mirror S M, which reflects it back to the 45° angle mirror M from which it is reflected in the direction of the observing eye E. If the spherical mirror S M is at its focal distance from h, all the rays b' b'', c' c'' will be parallel to the axial ray h d. If however the spherical mirror S M is moved nearer to h the rays b' b'' and c' c'' will diverge from h d, while if it is moved away from h the rays b' b'' and c' c'' will converge towards h d. The direction of the ray h d will always remain the same. By means of a screen A with small holes at d and c'' the desired axial ray of fixed direction and a ray whose inclination can be varied are obtained.

For greater precision in making the measurements of spherical aberration and measuring chromatic aberration the apparatus as actually constructed made use of monochromatic light.

Description of Apparatus

The optics of the apparatus used is shown in Figure 4. The image of a filament in bulb (A) (see Fig. 4), after passing through a collimator (B) and prism (C) was focused by lens (D) on a hole in the forty-five degree mirror (E).

Bulb (A) could be adjusted in any position by screws a, a, a (see photograph, Fig. 6).

The whole system (A B C) could be adjusted in any position by means of the tangent screw at (b) the elevating device at (c) and the tipping screws at (d, d) (see photograph, Fig. 6). The forty-five-degree mirror (E) could also be adjusted in any position by means of the lateral screws at (e, e) the elevating screw at (f) and the tangent screw at (g) (see photograph, Fig. 6).

The light passing through the small hole in (E) strikes a concave mirror (F) which is mounted in a slide that moves back and forth along the bed (G G), Fig. 5. By means of

the screws (h h) this mirror can be either tipped or moved laterally (see photograph, Fig. 6).

The light is reflected by this concave mirror (F) back to the forty-five-degree mirror and thence out in the direction (E H). It will be seen that when the mirror (F) is at a

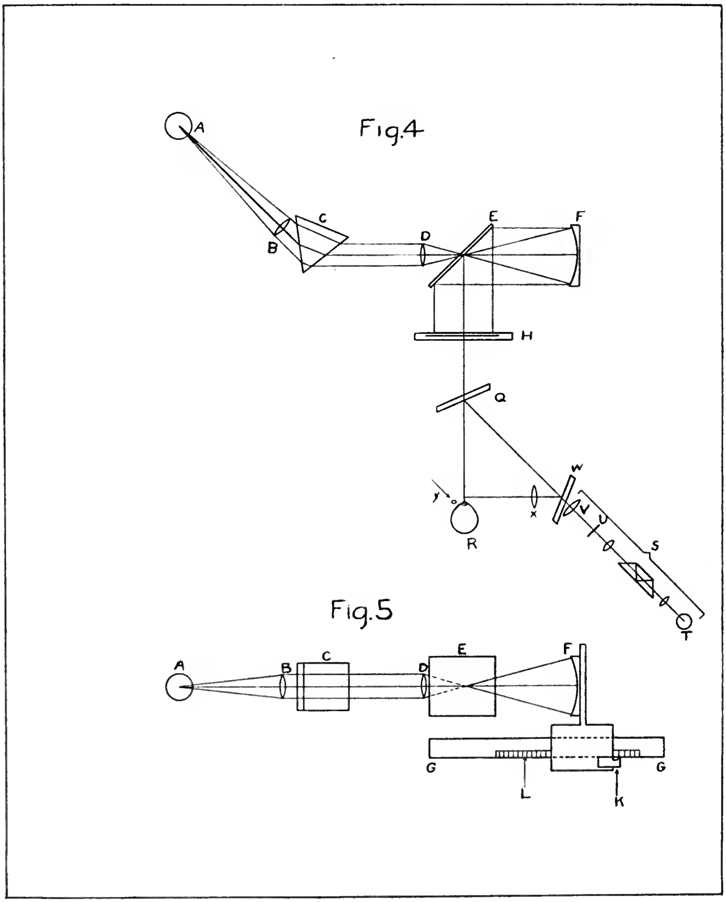

Fig. 4. Diagram of apparatus, plan.
Fig. 5. Diagram of apparatus, elevation.

distance from (E) equal to its focal length the light reflected in the direction (E) (H) will be parallel. If it is at a less distance, the light will be divergent; if at a greater distance, convergent. An indicator (K), Fig. 5, attached to (F) gives on the scale (L) marked on the bed the exact position of (F) from which the inclination of the reflected light can be calculated.

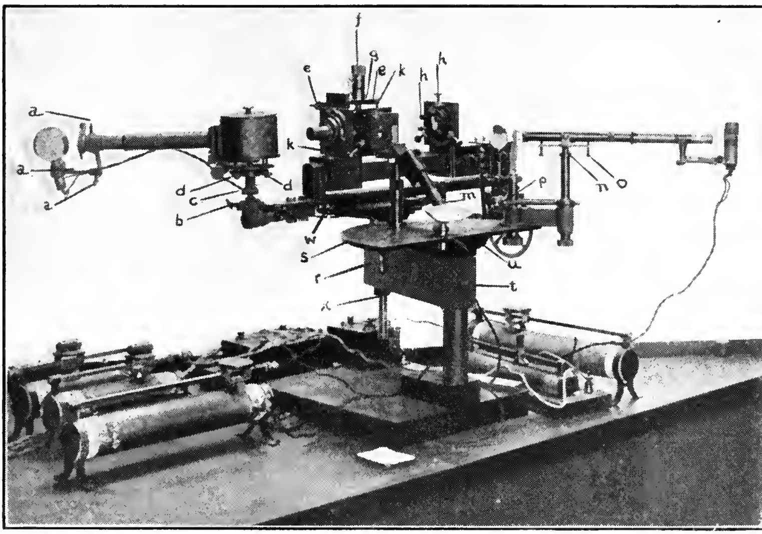

Fig. 6. Photograph of apparatus

At (H) Fig. 4, there is a block with a hole in it (see Fig. 7). In this block two slots are arranged at right angles to each other into which metal strips with slits cut as indicated can be shoved. This block can be adjusted up or down or sideways by the push screws (k) (k), (see photograph, Fig. 6). It can also be rotated in its mount around an axis perpendicular to the plane in which it lies. The width of the slits in the strips can be adjusted as desired. It was found

that if they were too narrow, diffraction bands became too prominent. After trying varying widths, slits of 0.5 mm. in width were used.

It will be seen that if strip (O), Fig 7, is shoved into block (H) all the light will be shut off except a narrow band which will come through the slit in (O). If strip (M) is then

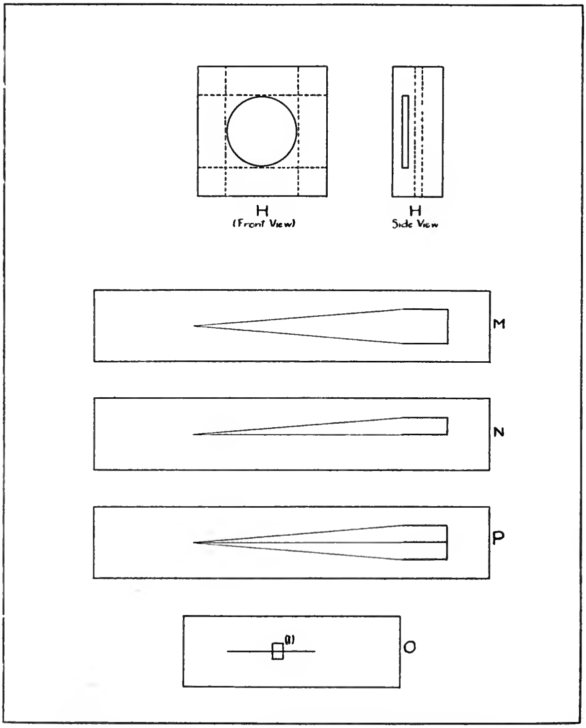

Fig. 7. Detailed drawing of block and strips

shoved into block (H) at right angles to strip (O) all the light on the narrow band will be cut off except where the slits in strip (M) coincide with the slit in (O), which will leave two beams whose cross-section is determined by the width of the slits in (M) and (O). By shoving (M) forward

and back, these two beams will move together or apart as desired. If strip (N) is used, two similar beams are obtained. But upon moving (N) forward and back, one of the beams will remain stationary and the other will move relative to it. Similar results are obtained with strip (P).

In this way two or more beams of light of any desired cross-section are obtained which can be given any desired inclination to each other, or whose inclination with any setting of the mirror (F) can be determined. Their separation can also be controlled and light of any wave-length can be obtained by changing the position of (A) and (B), Fig. 4, relative to that of the prism (C). We have therefore all the means necessary to determine the spherical aberration of a lens, granting that the lens can be held stationary. This was one of the most difficult problems to solve in connection with the eye and was accomplished as follows:

On a plane parallel placed at (Q), Fig. 4, a small white speck was placed. The plane parallel is mounted with optical wax on a small table which can be elevated or lowered, moved laterally, and tilted by screws (see photograph, Fig. 6). This speck was illuminated by focusing upon it the image of a small light placed at (m) (see photograph, Fig. 6). This illuminating system is fixed to the small table so that when the white speck is adjusted, the light which illuminates it moves with it. The head was positioned so that the eye of the observer came at (R), Fig. 4, the chin resting on a chin rest. With the eye accommodated for distant vision the speck images behind the retina. It appears on the retina where the retina cuts the cone of light as a circular disk of light, the border of which is determined by the edge of the pupil. When the speck is placed upon the optical axis of the system, a ray of light from (E) passing through the slits in, say (O) and (N), along the axis of the system will pass through the centre of the pupil, if the eye is so positioned that the image of the ray falls in the middle of the above described disk of

light. The shadow of the radiating cellular structure of the crystalline lens thrown on the retina by the speck at (Q) assists in centering in the middle of the disk. The slightest lateral movement of the head and eye will cause the image formed by the ray to move across the light disk.

To hold the accommodation constant, which is absolutely imperative, the system (S), Fig. 4, was used. It consisted of a light source (T), Fig. 4, the light from which after passing through a direct vision prism was focused on a vertical line, scratched on a silvered glass disk (u, Fig. 4), which is at the focus of the lens (V), Fig. 4. Monochromatic light was used to make the image sharper and to obviate any inclination to focus for different colors that exist in white light. The system was so placed that with the eye properly positioned the monochromatic line which appeared to be at infinity was visible by reflection from the plane parallel (Q). The system could be raised, lowered and tipped by adjustments (n and o) (see photograph Fig. 6), and could be turned laterally by a fine tangent screw at (p). The line (U) can be placed at any apparent distance from the eye by changing its distance from (V). In all readings made to date the apparent position of (U) was at infinity.

For directing rays into the eye obliquely that part of the apparatus designated by (A), (B), (C), (D), (E), (F), (G), and (H) is mounted on an arm, see (r), Fig. 6, which revolves about a vertical axis the centre of which lies directly below the nodal point of the eye when it is positioned. The semicircular plate, see (s) Fig. 6, is marked in degrees and an indicator attached to the above-mentioned arm shows in degrees the obliquity at which the rays strike the eye. A set screw at (t), Fig. 6, enables this movable system to be locked in any desired position.

When rays are put into the eye obliquely it is necessary that the position of the eye be also fixed along the axis of vision, *i. e.*, that there shall be no forward and backward movement of the eye. This is accomplished by putting a

half silvered surface at (W), Fig. 4. The monochromatic accommodation line from system (S) will be visible through the half silvered surface. An eye positioned at (R) will see reflected from the front surface of the plane parallel (Q) and the half silvered plate (W) a profile image of itself. A lens (x) is placed at its focal distance from the eye so that this profile image of the eye will be at infinity and can be seen sharply when the eye is focused on the monochromatic line from the system (S). It was found more convenient to put an illuminated spot at (y), Fig. 4, close to the nose on the farther side of the cornea from (W.) This illuminated spot is seen reflected from the surface of the cornea, appearing like a new moon. The slightest forward or backward movement of the head will cause this moon-shaped image to move across the circle of light formed on the retina by the illuminated speck on (Q).

A revolving drum is attached directly under the bed (G G), see (u), Fig. 6. A sheet of paper can be placed around and attached to the drum by a metal strip. The indicator (K) is extended down so that when it is pressed, a knife-edge point will make a mark on the paper.

Before taking readings, the concave mirror (F), Fig. 4, is set to give parallel light and the knife-edge point is lightly pressed on the paper and the drum revolved. This leaves a line on the paper. When readings are made by pressing the knife-edge point into the paper—the drum being turned slightly between each reading—the position of the mirror in front or behind its focal position is given. This saves considerable time, and makes it unnecessary to turn on a light while making observations.

It was believed that in measuring oblique astigmatism it would be of advantage to have another zonal ray whose inclination could be varied independently of the zonal ray from mirror (F). To accomplish this a mirror similar to (F) was made with a slot cut in it as shown in Fig. 8. This allowed the light from the hole in (E) to pass through it and

strike a mirror with a longer focus which travelled on the bed (G G) in the rear of (F). The light was reflected from this rear mirror back through the slot in (F) to the eye. Up to the present no use has been made of this elaboration except in attempts to perfect our methods of measuring spherical aberration where it was not found to be advantageous.

Method of Taking Readings of Spherical Aberration

Various methods of taking readings were tried out.

The apparently simplest one was to use strips (N) and (O), Fig. 7, in the block (H) with a monochromatic light source. These would give an axial ray and another ray which would strike the eye at any desired distance from the axis. When the eye was properly positioned and the mirror (F) set for parallel light, the images from these two rays would not coincide on account of spherical aberration. Mirror (F) could then be moved until they did coincide and the inclination of the ray determined, which would give the spherical aberration for the zone tested.

This method was used by Dr. Chapman in making the readings given in Table I. Though good, it lacked accuracy from the fact that the images formed by the rays are relatively large, due to the diffraction bands occasioned by the small dimension of the source and of the holes from the combined slits. The displacement of the two spots on the retina was very evident, but it was difficult to judge when they were exactly superimposed. The holes could not be made larger without making the cross-section of the rays too great to measure the small separation in zones which was desired.

It was thought it might be easier to make this exact superimposition if one of the images was one color and the other another. This was accomplished by focusing another source of different color on the hole in (E) by reflection from the face of the prism (C) and putting small pieces of different

monochromatic filters over the holes in the slits. This gave slightly better results.

TABLE I

Spherical Aberration. (Dr. Chapman.)

Observer, Dr. Chapman. Right eye, vision normal. No corneal astigmatism. Both eyes treated with homatropine, pupil dilated to about 7.5 mm. Accommodation relaxed. Focal length of mirror (F) = 71.9 mm scale reading 16.40. Hole in 45° plate (E) is at 92.1 scale reading. Distance from eye to mirror (F) = 277 mm.

Wave-length	Zone distance from axis, mm	Average scale readings, mm	Calculated object distance in front of eye, V′ mm	Calculated distances behind retina where incident parallel rays cut axis, mm
Red, 6560..........	1.0	167.3	— 1361	0.22
	1.5	165.8	— 2667	0.12
	2.0	165.1	— 4495	0.06
	2.5	166.4	— 1949	0.16
	3.0	167.4	— 1315	0.22
	3.5	167.5	— 1272	0.23
Yellow, 5890......	1.0	164.0	∞	0.00
	1.5	163.0	+ 5375	—0.05
	2.0	163.5	+10547	—0.02
	2.5	164.3	—17023	0.02
	3.0	166.6	— 1783	0.17
	3.5	166.9	— 1578	0.19
Blue, 4860..........	1.0	161.8	+ 2555	—0.11
	1.5	159.6	+ 1380	—0.20
	2.0	161.1	+ 1988	—0.14
	2.5	162.4	+ 3436	—0.08
	3.0	163.7	+17437	—0.01

For calculation of V′ equation $1/V = 1/71.9 - 1/U$ was used. U = scale reading minus 921, and V′ = 277 —V.

A typical set of readings from which one of the above averages was determined contained sixteen readings. Their average was 16.43. The largest reading was 166.0, the smallest 161.9.

Another method tried was to vary the widths of the slits so that a rectangular instead of a square hole was formed, the long dimension of one hole being at right angles to that of the other. The short dimension was made so small that considerable extension of the image was produced by diffrac-

TABLE II

Spherical Aberration. (*Dr. Chapman.*)

Conditions were the same as in Table I except that Dr. Chapman's pupils were not dilated and he used light of different wave-lengths in the two beams, and apertures of slits were ½ x ¼ mm with the long dimension of one at right angles to that of the other.

Wave-length	Zone distance from axis, mm	Average scale readings, mm	Calculated object distance in front of eye, V′ mm	Calculated distances behind retina where incident parallel rays cut axis, mm
Red, 6560	0.50	170.8	— 620	0.48
	0.75	168.6	— 986	0.30
	1.00	167.1	— 1530	0.20
	1.50	165.5	— 3308	0.09
Yellow, 5890	0.50	166.1	— 2324	0.13
	1.00	164.3	—17090	0.02
	1.50	163.1	+ 5882	—0.04
Blue, 4860	0.50	164.2	—25710	0.02
	1.00	161.8	+ 2488	—0.12
	1.50	159.7	+ 1340	—0.21

$V' = 212 - V$.

A typical set of readings from which one of the above averages was determined contained five readings. Their average was 164.3. The largest reading was 164.7, the smallest 163.7.

Dr. Chapman made the following settings with the slits removed, *i.e.*, with his pupil filled with light. Accommodation relaxed.

Wave-length	Average scale readings, mm	Calculated object distance in front of eye, mm	Calculated distance behind retina where incident parallel rays cut axis mm
Red, 6560	166.3	—2000	0.144
Yellow, 5890	164.9	—5600	0.052
Blue, 4860	162.8	4600	—0.059

$V' = 277 - V$.

tion. The result was two line images at right angles to each other which when superimposed appeared like a cross. This method was better, and together with different colored

spots, was used by Dr. Chapman in observations given in Table II.

The method finally adopted was as follows: Instead of obtaining our axial image from a ray of small cross-section passing along the axis, the image of the fine fixation line from system (S), Fig. 4, was used. Its image, which was formed by light coming through the entire pupil, was much smaller than the image formed by the ray of small cross-section and enabled much more accurate settings to be made. The centre of the fixation line was carefully adjusted in the middle of the hole in (E) while being observed in a telescope. Strips (M) and (O), Fig. 7, were used with this method. A small plate, see (I) (O), Fig. 7, was placed on strip (O). By sliding strip (O) this small plate would cut off either side of the "V" in (M) or leave both sides open as desired. This enabled the zones on both sides of the eye to be tested separately or together. Light of only one color was used. The observations taken in this way are given in Tables III, IV, and V.

Measurements

The first measurements were made by Dr. Chapman, whose vision is normal, at Clark University, Worcester, Mass., in July, 1917. He measured the differences in aberration of the zones directly above the axis. He used two beams, one on the axis and a movable one above. Instead of a plane parallel at (Q), Fig. 4, he used a very thin cover glass and in place of a monochromatic source he focused on very small point sources at infinity illuminated by white light.

In making the readings given in Table I, he dilated his pupil with homatropine and used beams 0.5 mm. in cross-section and the same colored light in both beams. He made the readings given in Table II with normal pupil, using light of different color in the two beams with beams which were narrower in one cross-section than in the other,

giving the effect of two short lines at right angles to one another.

Fig. 9 shows in diagrammatic form the distances in front and behind the retina at which light of the different wave-lengths is focused by the different zones.

Fig. 13 shows the actual form of the ray bundles due to spherical aberration for the three colors. In making the figures it was assumed that the aberrations on the lower

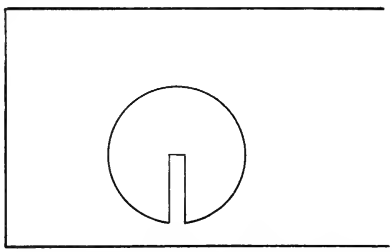

Fig. 8. Detail of front mirror used in obtaining two rays with independently variable inclination.

half of the vertical meridian were the same as those on the upper half. This accounts for the symmetry of the bundles.

The displacement along the axis of the curves in Fig. 9 and the bundles in Fig. 13 for different wave-lengths is due to the axial chromatic aberration of the eye which will be treated in more detail later.

The measurements by Mr. Ames were made in 1919 at Dartmouth College, Hanover, N. H. He had considerable trouble getting consistent readings, especially for the zones near the axis. After much experimentation it was found that this was due to failure to get the axis of his eye on the axis of the optical system of the apparatus. This was in turn due to the decentration of his pupil. After the axis of his eye had been determined, his readings showed very little variation. The method of determining this was as follows:

Two beams with the separation of 1 mm. were obtained

TABLE III

Spherical Aberration. (Mr. Ames.)

(Horizontal Meridian.)

Observer Mr. Ames, right eye, slight myopia and astigmatism. Pupil normal. Accommodation relaxed. Focal length of mirror (F) =71.9 mm; scale reading when set for parallel light, 17.62 cm. Distance eye to mirror (F) = 205 mm.

Wave-length	Zone distance from axis mm	Average readings (distances from focus of mirror), mm		Calculated object (distances in front of eye), mm		Calculated distance behind retina where incident parallel rays cut axis, mm	
		Temp.	Nasal	Temp.	Nasal	Temp.	Nasal
Red, 6563	0.50	1.71	1.56	— 2800	— 3100	0.103	0.093
	0.75	1.58	1.38	— 3070	— 3570	0.095	0.081
	1.00	1.98	1.03	— 2360	— 4850	0.124	0.059
	1.50	0.71	—0.12	— 7150	∞	0.040	0.000
	2.00	0.39	+0.03	—13100	∞	0.022	0.000
	2.50	0.31	1.05	—16700	— 4750	0.017	0.060
	3.00	0.60	0.87	— 8400	— 5800	0.034	0.049
Yellow, 5893	0.50	+0.65	+0.40	— 7750	—12750	0.037	0.022
	0.75	1.26	0.12	— 3950	∞	0.073	0.000
	1.00	—0.08	—1.04	∞	5300	0.000	—0.055
	1.50	—1.58	—2.04	3500	2700	—0.083	—0.108
	2.00	—1.05	—1.56	5250	3550	—0.056	—0.080
	2.50	—0.76	—0.79	7070	6850	—0.042	—0.043
	3.00	—0.54	—0.46	9750	11450	—0.031	—0.026
Green, 5461	0.50	—1.02	—0.78	5400	6900	—0.054	—0.042
	0.75	—0.99	—0.72	5550	7450	—0.052	—0.039
	1.00	—2.39	—2.62	2350	2170	—0.123	—0.134
	1.50	—3.72	—3.95	1600	1510	—0.180	—0.191
	2.00	—3.90	—3.56	1530	1670	—0.188	—0.173
	2.50	—3.16	—2.59	1850	2200	—0.156	—0.132
	3.00	—3.37	—2.68	1750	2130	—0.165	—0.136
Blue, 4861	0.50	....	....	2000	2252	—0.145	—0.128
	0.75	....	....	1754	1949	—0.166	—0.149
	1.00	—6.26	—6.72	1035	978	—0.276	—0.292
	1.50	—6.72	—6.73	978	977	—0.292	—0.292
	2.00	—6.20	—5.97	1043	1075	—0.273	—0.266
	2.50	—5.50	—4.85	1147	1273	—0.250	—0.225
	3.00	—5.98	—5.79	1073	1100	—0.267	—0.260

with slits (M) and (O), Fig. 7. The mirror (F) was pushed slightly in front of its focus position so that the images from

the two beams were just separated. A lateral movement of the eye caused the images to move relative to each other. A position was found where movement towards either side

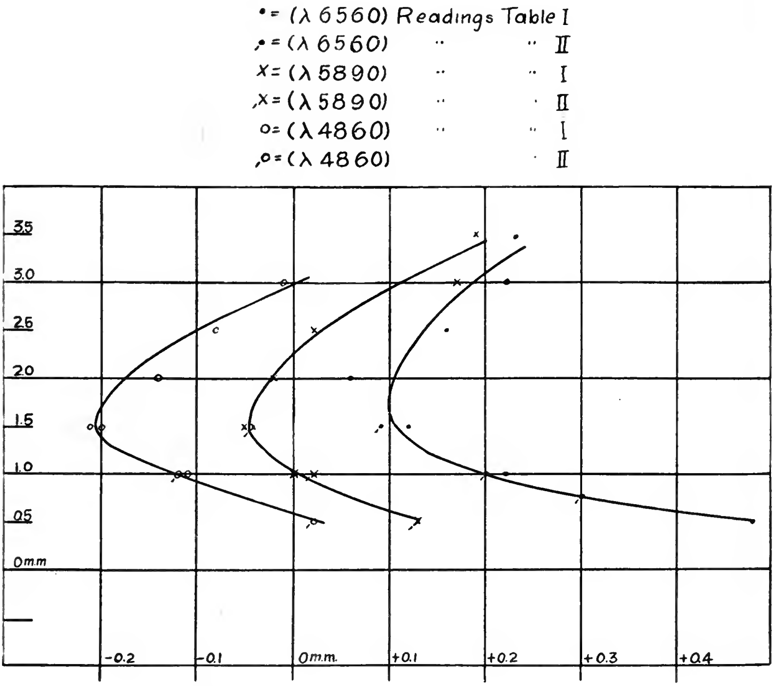

Fig. 9. Spherical aberration curves from measurements of Dr. Chapman's eye. Abscissae represent 0.1 millimeter from retina. Ordinates represent distance in millimeters of zone from axis.

caused the images to come together. In this middle position the beams were coming into the eye at equal distances from the axis and the point half way between is the axis of the lens system. When the eye is so placed that the monochromatic line from system (S), Fig. 4, falls on this point and is carefully kept there, very consistent readings could be obtained.

Table III shows Mr. Ames' readings for the different wave-lengths for the different zones, both temporal and nasal. Table IV shows his readings for the zones in the vertical meridian. Table V shows his readings for the temporal and nasal zones combined and was made as follows:

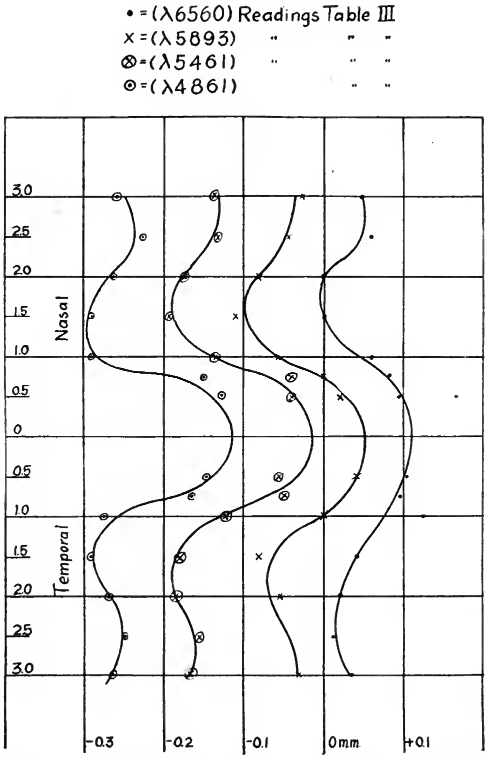

Fig. 10. Spherical aberration curves from measurement of horizontal meridian of Mr. Ames' eye.

Slits (M) and (O), Fig. 7, were used, both sides of the "V" in (M) being left open. Mirror (F) was moved until both spots superimposed. To insure they were superimposed, slit (O) was pushed back and forward so that

TABLE IV
Spherical Aberration. (*Mr. Ames.*)
(Vertical Meridian.)
(Conditions the same as in Table III.)

Wave-length	Zone distance from axis, mm	Average readings (distances from focus of mirror), mm		Calculated object distances in front of eye, mm		Calculated distances behind retina where incident parallel rays cut axis, mm	
		Lower	Upper	Lower	Upper	Lower	Upper
Red, 6563	0.5	+1.07	+1.76	—4670	—2730	0.062	0.107
	1.0	—0.53	+0.15	9900	∞	—0.030	0.000
	1.5	—1.03	—1.27	5350	4370	—0.054	—0.067
	2.0	—0.82	—1.56	6580	3540	—0.045	—0.080
	2.5	—1.36	—2.04	4070	2690	—0.072	—0.106
	3.0	—2.12	—3.02	2600	1925	—0.112	—0.151
Yellow, 5893	0.5	—0.53	—0.41	9900	13000	—0.030	—0.022
	1.0	—2.82	—1.32	2040	4200	—0.142	—0.070
	1.5	—3.01	—2.66	1930	2150	—0.150	—0.135
	2.0	—3.31	—4.17	1775	1440	—0.163	—0.200
	2.5	—3.14	—3.57	1860	1660	—0.156	—0.174
	3.0	—4.63	....	1320	....	—0.217	....
Green, 5461	0.5	—1.59	—1.09	3470	5050	—0.084	—0.058
	1.0	—3.22	—3.44	1820	1715	—0.158	—0.168
	1.5	—4.82	—4.82	1275	1275	—0.225	—0.225
	2.0	—4.81	—5.35	1280	1175	—0.224	—0.244
	2.5	—4.92	—5.47	1255	1155	—0.228	—0.248
	3.0	—5.99	....	1075	....	—0.266	....
Blue, 4861	0.5	—5.24	—5.88	1193	1087	—0.240	—0.263
	1.0	—7.05	—6.31	940	1027	—0.303	—0.277
	1.5	—8.61	—8.04	807	848	—0.352	—0.335
	2.0	—9.09	—8.60	775	808	—0.367	—0.352
	2.5	—9.26	—7.70	763	877	—0.373	—0.325

plates (I) (O), Fig. 7, cut off first one image and then the other. If one image came exactly where the other had been, the setting was correct. If there was the slightest jump in one way or the other, a more careful setting was made.

In all readings the wave-length of the vertical monochromatic accommodation line at infinity was (λ6563). Owing

TABLE V.
Spherical Aberration. (*Mr. Ames.*)
(Horizontal Meridian.)
(Conditions the same as in Table III. Readings for corresponding nasal and temporal zones combined as described on page 21.)

Wave-length	Zone distance from axis, mm	Average readings (distances from focus of mirror), mm	Calculated object distances in front of eye, mm	Calculated distances behind retina where incident parallel rays cut axis, mm
Red, 6563..........	0.50	+0.21	∞	0.000
	0.75	+0.35	—14750	0.018
	1.00	—0.51	10300	—0.028
	1.50	—0.96	5660	—0.051
	2.00	—1.09	5050	—0.058
	2.50	—0.02 nasal only	∞	0.000
Yellow, 5893	0.50	—1.08	5080	—0.058
	0.75	—0.81	6660	—0.044
	1.00	—1.61	3420	—0.086
	1.50	—2.60	2190	—0.133
	2.00	—2.35	2390	—0.122
	2.50	—1.27 nasal only	4350	—0.068
Green, 5461........	0.50	—2.76	2080	—0.140
	0.75	—2.77	2070	—0.140
	1.00	—3.70	1610	—0.180
	1.50	—4.28	1415	—0.023
	2.00	—4.32	1400	—0.205
	2.50	—2.95 nasal only	1960	—0.148
Yellow, 5893 (later reading)..	0.50	—0.50	10500	—0.027
	0.75	—0.85	6400	—0.046
	1.00	—1.75	3150	—0.093
	1.50	—2.66	2130	—0.137
	2.00	—2.49	2270	—0.128
	2.50	—1.78	3090	—0.095

to his slight myopia, Mr. Ames was unable to get a sharp image if a light of a shorter wave-length was used.

The curves in Figs. 10, 11 and 12 show these measurements in graphic form.

It will be seen that the part of the curves showing the spherical aberration in the outer zones in the vertical me-

ridian (Fig. 11) are displaced further forward than those in the horizontal meridian (Fig. 10). Difference in shape of the curves in the two meridians is probably due to asymmetry in shape of the cornea similar to that found by Gullstrand[1] caused by corneal astigmatism.

This corneal astigmatism, or the difference in refraction for Mr. Ames' eye in the horizontal and vertical meridian, is shown by the difference in the position of sharp focus of a vertical and horizontal line source which is as follows:

Wave-length	Vertical line, calculated object distance, mm	Horizontal line, calculated object distance, mm	Vertical line, calculated image distance from retina, mm	Horizontal line, calculated image distance from retina, mm	Difference mm
Red, 6563	286000	4030	0.001	0.072	0.071
Yellow, 5893	3000	1670	0.095	0.172	0.077
Blue, 4861	1100	843	0.260	0.342	0.102

It is also shown in the difference in readings made with a horizontal and vertical beam of light extending across the whole pupil. The following readings were made with strip (O), Fig. 7, placed in a horizontal and vertical position. Accommodation relaxed.

Wave-length	Horizontal slit calculated object distance, mm	Vertical slit calculated object distance, mm	Horizontal slit calculated image distance from retina, mm	Vertical slit calculated image distance from retina, mm	Difference mm
Red, 6563	19000	4100	0.015	0.059	0.044
Yellow, 5893	2300	1585	0.125	0.181	0.056
Blue, 4861	1010	822	0.287	0.347	0.060

The curves in Fig. 12, though similar in shape and separation to those in Fig. 10, are displaced toward the left. It is believed this is due to a slight difference in accommodation;

[1] Helmholtz, *Physiologischen Optik*, 3rd Ed., pp. 268 and 269, Vol. I.

these measurements being taken about six months later than those shown in Fig. 10.

Figs. 13 (a), (b), (c) show the actual form of the ray

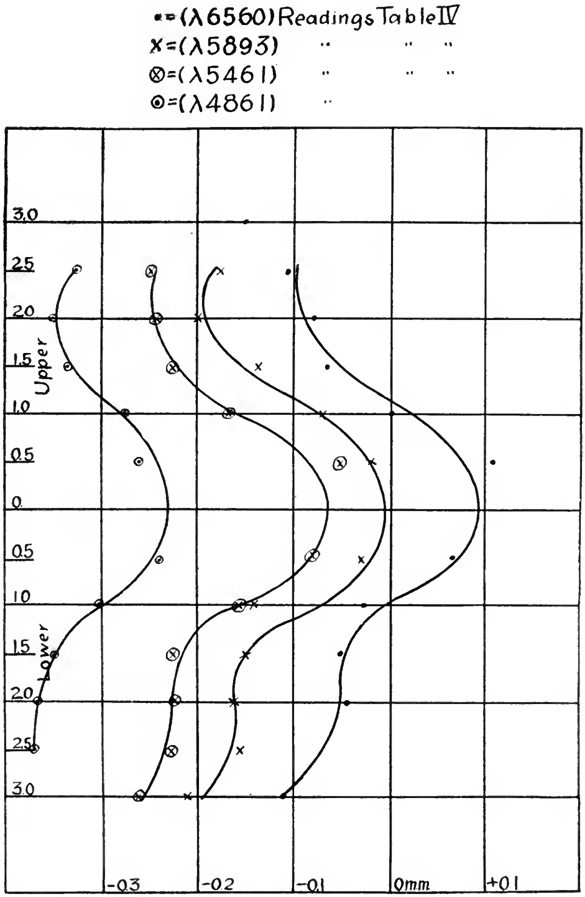

Fig. 11. Spherical aberration curves from measurements of vertical meridian of Mr. Ames' eye.

bundles due to spherical aberration. Fig. 13 (a) shows those formed by the horizontal meridian, Fig. 13 (b), those by the

vertical meridian and Fig. 13 (c), those formed by the combined horizontal and vertical meridian. It will be noted

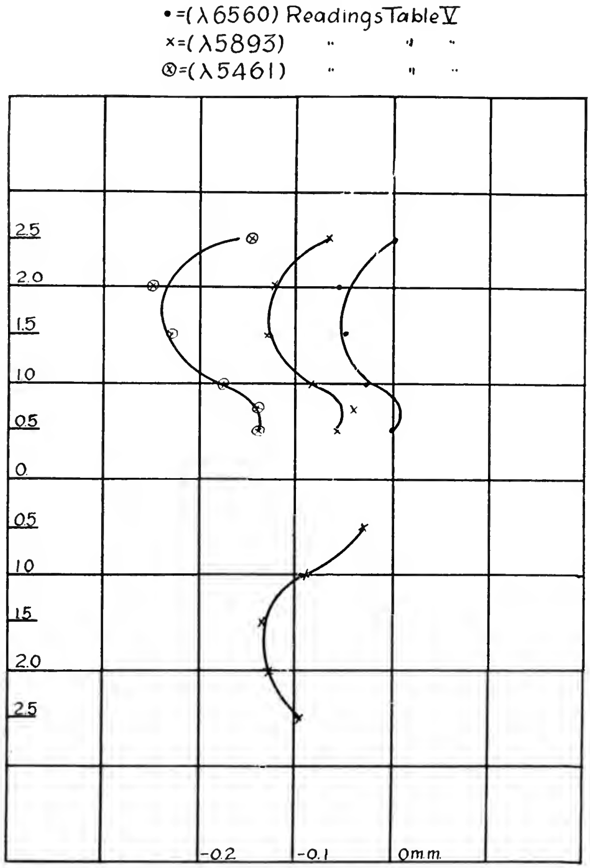

Fig. 12. Spherical aberration curves from measurement of horizontal meridian of Mr. Ames' eye, the aberration from corresponding zones on both sides of the axis being determined at the same time.

that the bundles for the different colors in the horizontal meridian are very similar to each other and also that those

in the vertical meridian, while similar to each other, are different from those in the horizontal meridian. The displacement of the bundles formed by the two meridians is due to the corneal astigmatism which has been mentioned.

It will be seen that while both Dr. Chapman's and Mr. Ames' curves are in general form similar, Dr. Chapman's curves differ from Mr. Ames'. That the spherical aberration should be different in the eyes of different individuals is in conformity with the measurements made by other methods; see Tscherning's *Physiological Optics* referred to above.

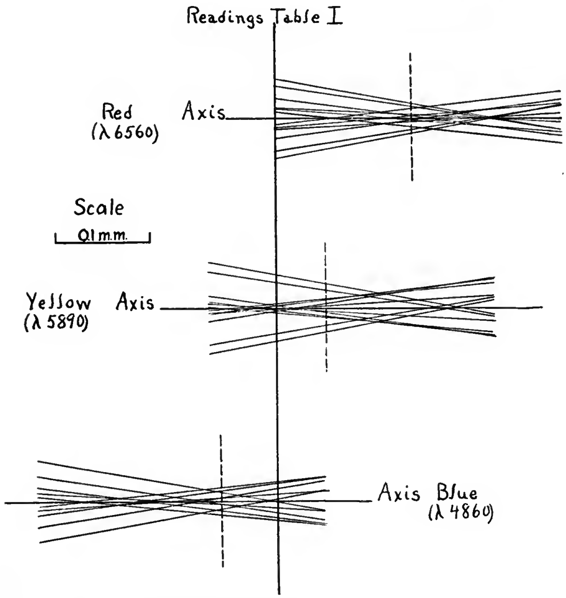

Fig. 13. Actual shape of spherical aberration bundles as constructed from measurements of Dr. Chapman's eye. The solid line shows the focus of a spot of white light positioned at infinity. The dash lines show the position of the retina in the bundles when the eye focused on infinity sees most sharply a spot of the given color.

The results in general form are similar to the results

found by other methods. The aberration is, however, considerably less than that calculated by Gullstrand; see p. 363, Vol. I, Helmholtz, *Physiologischen Optik* 3rd Ed.

There is a much mooted question as to whether the eye so

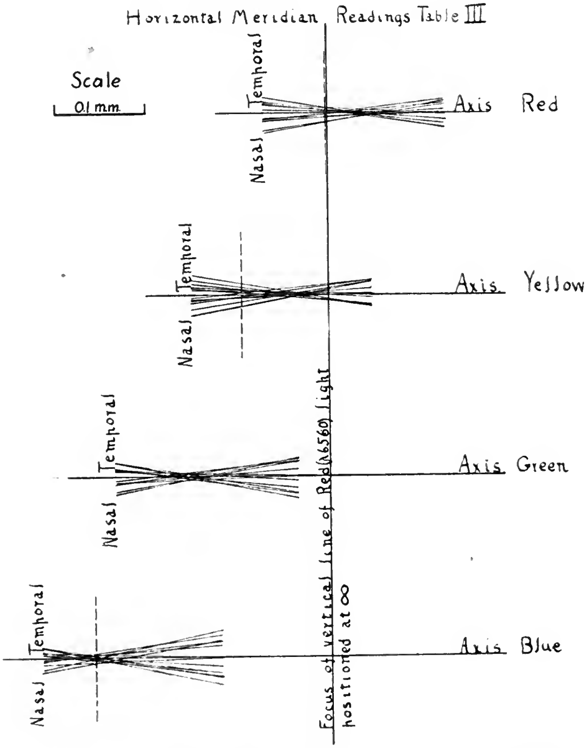

Fig. 13a. Actual shape of spherical aberration bundles as constructed from measurements in the horizontal meridian of Mr. Ames' eye. The dash lines show the position of the retina in the bundles when the eye focused on infinity sees most sharply a vertical line of the given color.

focuses that that part of the cone which has the smallest diameter falls upon the retina or that part where the section of the caustic due to spherical aberration is smallest. Both

Tscherning and Gullstrand believe that it is that part of the bundle where the caustic is smallest and not where the cone has the least diameter. The exact nature of the results obtained in this method of research make it possible to answer this question very definitely. For Dr. Chapman's and Mr. Ames' eyes there seems to be no question but that they focus approximately on that part of the bundle where the cone has the least diameter.

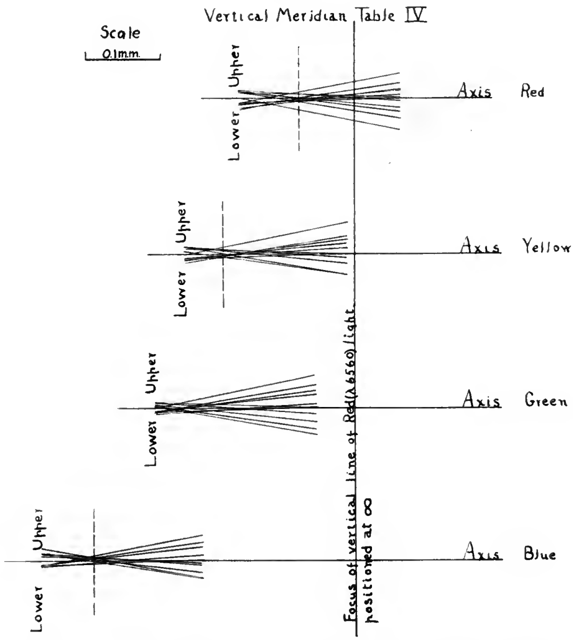

Fig. 13b. Actual shape of spherical aberration bundles as constructed from measurements in the vertical meridian of Mr. Ames' eye. The dash lines show the position of the retina in the bundles when the eye focused on infinity sees most sharply a horizontal line of the given color.

The long vertical line in Fig. 13 shows the position of Dr. Chapman's retina when he saw most sharply a white

source positioned at infinity. The long vertical lines in Figs. 13, 13a, 13b, and 13c show the position of Mr. Ames'

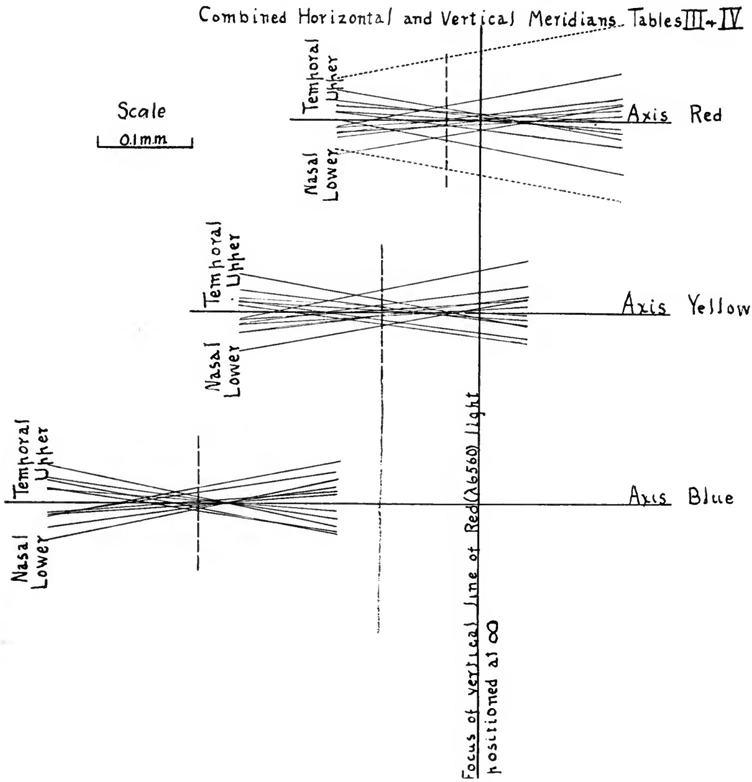

Fig. 13c. Actual shape of spherical aberration bundles as constructed from the combined measurements in the horizontal and vertical meridians of Mr. Ames' eye. The dash lines show the position of the retina in the bundles when the eye focused on infinity sees most sharply a spot of the given color. The dotted lines show the outside rays of a blue (λ 4860) bundle when the eye sees most sharply a red (λ 6560) spot.

retina when he saw most sharply a vertical red line positioned at infinity. The bundles show the position of the image

cones of point sources of different wave-length positioned at infinity, their distance from the vertical lines giving the chromatic aberration. The short vertical broken lines show the position of the image for the corresponding wave-lengths of an object placed at infinity. In the case of Fig. 13 this object was a point source; 13a a vertical line; 13b a horizontal line; 13c a point source.

Figs. 13, a, b and c, show that the retina shifts its position in the image bundle according to whether Mr. Ames is looking at a vertical or horizontal line or a point source. This is to be expected in view of the difference in the spherical aberration curve in the horizontal and vertical meridian. The sharpness of an image from a vertical line source is in the main governed by the aberrations in the horizontal meridian, that from a horizontal line source by those of the vertical meridian and that of a point by a combination of both. It will be noted in all cases, however, that the retina as indicated by the vertical dash lines falls approximately on that part of the image bundle where its diameter is smallest.

That this is usually the case would seem to be confirmed by the following observations by Dr. Proctor and Mr. Ames. With light entering the whole pupil the brightness of the source was made so low that it was just visible. It was then made to focus as sharply as possible by moving the mirror (F) while the accommodation of the eye was kept constant by observing the monochromatic fixation cross in system (S). The brightness of the source was then increased until it became bright enough to give a glare. No change in accommodation was perceptible, *i. e.*, the fixation line continued to be equally sharp and clear. Nor at any time while increasing the brightness of the spot could it be made to appear sharper or smaller by changing the focus of (F). It is believed that this could only be true if the eye was focused on the smallest part of the caustic, there would be a halo around it, invisible with very low illumination but

very bright with high. This halo would be larger than the smallest diameter of the cone and with a very bright source it would be expected that a smaller image could be obtained by a slight shift in focus which would bring that part of the cone which has the smallest diameter upon the pupil.

In view of the definite results it seemed possible that a lens could be made which would correct both the spherical and chromatic aberration resulting in a smaller image bundle. Such a lens is being designed. While it is realized it could not improve vision in an eye like Mr. Ames' where the corneal astigmatism is relatively large, it might correct the aberrations in one meridian. In an eye with no corneal astigmatism it might possibly result in improved vision.

As has been stated, the readings that have been made are scarcely more than preliminary. The spherical aberration of a large number of eyes should be measured. This should be done for near and intermediate and distant accommodation. The measurements should also be made over at least four different meridians of the eye. The angle between the visual and optical axis (angle alpha) of each observer should be determined as well as the corneal astigmatism and the relationship between these factors and the spherical aberration noted.

AXIAL CHROMATIC ABERRATION

Introductory

Chromatic aberration is the focusing of rays of different wave-length at different distances along the axis. This is shown in Figure 14. R represents a bundle of light coming from a white light point source, made up of light of all wave-lengths. Due to the nature of the lens system of the eye, light of different wave-length does not come to a focus at the same point on the axis. The light of shorter wave-length (*i. e.* blue) focuses nearer the lens at (b) while that of long wave-length (*i. e.* red) focuses farther away from the

lens at (r). Light of intermediate wave-length (*i. e.* yellow) will focus on the retina at (y). It is evident that the ray bundle where it cuts the retina at a a′ is spread over a much larger area than if this defect did not exist.

The literature on axial chromatism of the human eye is very voluminous. Tscherning gives a short chapter to it in his *Physiologic Optics.*

One method to determine quantitatively the axial chromatism of a lens is to ascertain the difference in inclination of rays of varying wave-length which come to the same

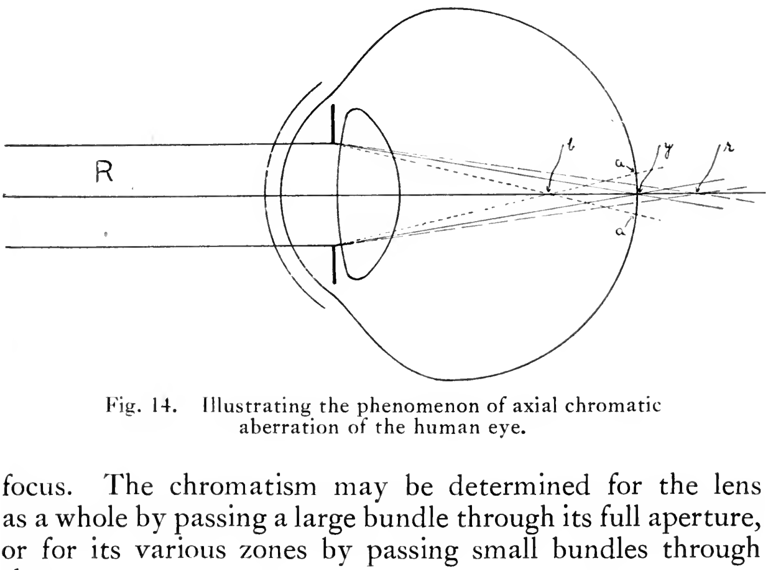

Fig. 14. Illustrating the phenomenon of axial chromatic aberration of the human eye.

focus. The chromatism may be determined for the lens as a whole by passing a large bundle through its full aperture, or for its various zones by passing small bundles through them.

The first method is, as far as is known, the only one that has been used up to date in measuring the eye. Nutting[2] was the last to use this method and found the mean axial chromatism for seven eyes between the C and F lines to amount to 0.99 D. Young estimated it to be 1.3D. Fraun-

[2] *Proceedings of the Royal Society* A, Vol. 90 (1914).

hofer found it 1.5 to 3 D for the range of the visible spectrum.

Method of Making Measurements

The apparatus above described is admirably fitted to make such measurements. The method is as follows: With the slits removed from (H), Fig. 4, so that the whole pupil will be filled with light, the eye is accommodated on the monochromatic fixation line in system (S), Fig. 4. Monochromatic light of a given wave-length is focused through the hole in (E), Fig. 4. Mirror (F), Fig. 4, is then moved until the sharpest image is formed on the retina. The reading will give the inclination of the rays necessary for light of that wave-length to come to focus on the retina. The wave-length of the light coming through the hole in (E) is then changed and a new reading taken. In this way the axial chromatic aberration curve for the different wave-lengths can be determined.

The amount of the aberrations varying from 0.72D to 0.98D correspond with the figures found by others as given above.

The method followed by Nutting is practically the same as given above, except that he did not use a monochromatic accommodation control. He also went further in using a greater number of different wave-lengths which enabled him to plot more accurately the entire curve. He finds this curve in some cases considerably flattened through its central portion, *i. e.*, on both sides of the D line and assumes that this is due to the eye being more or less corrected.

Dr. Proctor, Mr. Murch and Mr. Ames made readings for a similar set of wave-lengths, the results of which are given in Table VI and Fig. 15. It will be seen that they did not find any flattening of the curve. It was suggested[3] that the flattening found by Nutting was due to his using a chromatic, *i. e.*, white light accommodation object. With an object illuminated by white light the eye normally

[3] *Journal Optical Society of America* Vol. X, No. 1 pages 51 and 52.

accommodates so that the yellow light which is of the greatest intensity focuses on the retina. A slight change of accommodation which would cause a slightly more reddish or more greenish light to focus on the retina would not perceptibly change the visibility of the object. There would be a tendency to make such a shift where the eye

TABLE VI

Chromatic Aberration, Accommodation Relaxed. Monochromatic Fixation.

Wave-length	Mr. Ames Fixation, λ=6560		Dr. Proctor Fixation, λ=5600		Mr. Murch Fixation, λ=6560	
	Average scale readings	Retina to focus, mm	Average scale readings	Retina to focus, mm	Average scale readings	Retina to focus, mm
7000	+0.04	0.000	3.46	—0.226	— 2.24	0.127
6500	—0.71	0.038	2.30	—0.147	— 3.60	0.174
6000	—1.55	0.081	0.64	—0.037	— 6.70	0.291
5500	—3.5	0.170	—0.31	+0.017	— 8.30	0.345
5090	—5.8	0.260	—1.90	+0.103	—11.20	0.425
4650	—8.45	0.347	—4.81	+0.248	—14.70	0.508

was trying to focus a monochromatic source of a wave-length near the D line. This would explain the flattening in this region which Nutting found. The fact that neither Dr. Proctor or Mr. Ames or Mr. Murch found such a flattening when they used a monochromatic accommodation object is confirmation of this. Since making that suggestion, Dr. Proctor and Mr. Ames have remeasured the chromatic aberration of their eyes using a white light accommodation object. They found that the chromatic aberration curves had no more flattening in their central portions than when they used a monochromatic accommodation object. The suggested explanation therefore cannot be the correct one.

The determination of the axial chromatism for different zones was found when the spherical aberration of the eyes for different colors was measured. It is shown in Tables I, II, III, IV and V and in Figs. 9, 10, 11, 12, 13 (a), (b)

and (c). In making the observations shown in Table I and Fig. 9 Dr. Chapman used an accommodation object illuminated by white light. But in making the readings given in Table II and Fig. 9, his axial ray was of one wave-length and his zonal ray of another. With a blue zonal ray he used a yellow axial ray; with a yellow zonal ray, a red axial ray; with a red zonal ray, a green axial ray.

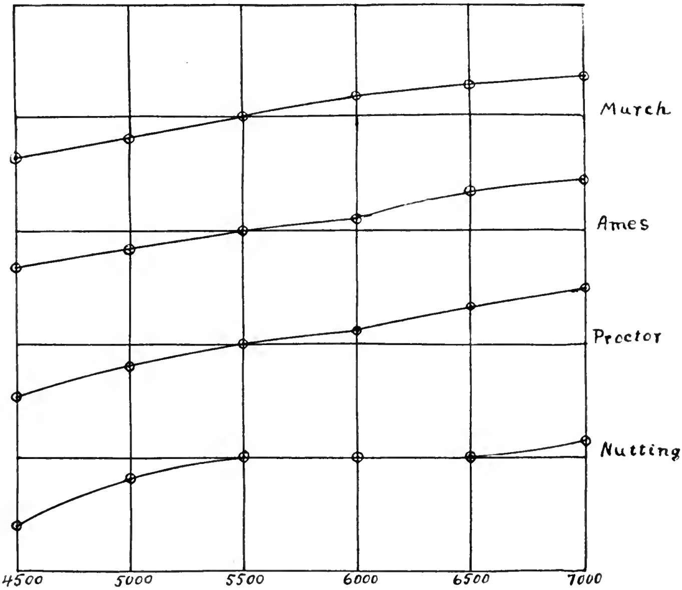

Fig. 15. Showing the form of the axial chromatic aberration curve for different wave-lengths as found by different observers. Nutting found a flattening of the curve from λ 5500 to λ 6500. The authors do not find this central flattening.

Figs. 13 and 13 (a), (b) and (c) give a very clear idea of the chromatic aberration in the eye. They also give a very definite measure of its size. In Fig. 13 (c), top figure, the dotted lines represent the outside rays of the blue bundle when the eye is focused on red. The question of

the actual size of spherical and chromatic aberration image bundles is of considerable interest. It is our intention to treat the matter in a later paper.

As was said in respect to spherical aberration, the work that has been done in axial chromatism is hardly more than preliminary. Readings should be taken on a large number of eyes with different accommodations and with dilated and normal pupil. And measurements should be made with a large number of different wave-lengths.

Two special problems of interest are: 1st, a more positive determination of whether or not a flattening of the chromatic curve, such as Nutting found, exists; 2nd, a more definite determination of the chromatic aberration for the different zones.

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Declination

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A COMPREHENSIVE functional examination of the eyes is by no means simple. It involves a careful investigation of all the factors which unite to make the visual act one of very complex character. Theoretically it should include such tests as may establish the presence or absence of defects, not only in the eyeballs themselves, but in the visual tracts and the nervous centers of vision.

Given, however, the freedom of the visual organ from pathological disturbance, it becomes a matter of considerable importance to determine its efficiency as an optical instrument.

Little need be said with regard to the determination of the refractive conditions of the two eyes. Refraction has become a fairly exact science. Methods of examination in this field have become more and more refined, so that good refractionists are common, both in the medical and the optical professions. With unfortunate frequency, however, the determination of the refractive condition is considered final. The fitting of a proper correcting lens for each individual eye seems to be all sufficient, and with this correction the examination is concluded and the patient dismissed.

Binocular vision is essentially a muscular function. It is the highest expression of the muscular sense. In the study of this function one is quickly led to assign to the "picture on the retina" a position of secondary importance. A careful analysis of the points in the field of regard which are seen distinctly when the eye is steadily fixing any single point is convincing proof that the region of clear vision on the retina is extremely limited. All other points impressed upon the retina, though indistinctly seen, have, however, the important function of showing the way the eyes must travel in order to bring them consecutively into the region of clear vision. Our visual knowledge of space, then, of distance, form and depth, is thus gained by means of

ocular movements, either actually performed, or of which an unconscious estimate based upon experience is made. It is, therefore, very evident, that if we are to interpret these movements properly and thus gain an accurate conception of the relationship of objects in space, the muscular adjustments of the two eyes with regard to each other must be of the greatest exactitude.

Departures from the most favorable muscular adjustments are common. In fact the observation of those accustomed to look for them is that they are of quite as frequent occurrence as errors of refraction. A functional examination, then, which stops at the determination of the refractive conditions and fails to investigate the conditions of binocular adjustments is an examination only half performed.

There are three forms which these departures from most favorable adjustment may assume. This, of course, excludes false adjustments due to paralysis, or to pathological conditions affecting the musculature or parts which might interfere with the normal action of the muscles. These three forms of anomalies are expressions of disturbances of three important relations of the two eyes: the relation of the visual axes to each other; the adjustment of the normal plane of regard; and the relation of the retinal meridians of the eyes to the corresponding meridians of space.

Disturbances in the relations of the visual axes are manifested either as heterophoria—conditions in which binocular vision is habitually maintained—or as heterotropia in which there is actual deviation of the visual axes from parallelism. The latter condition, a visible squint, is usually too conspicuous to escape detection. Heterophoria and the lesser heterotropic deviations are, as a rule, readily determined by means of the phorometer.

The adjustment of the normal plane of regard is dependent upon the rotating ability of the eyes in various directions. Adjustments of this plane which are too high or too low, designated as anophoria or katophoria, are

unquestionable hindrances to easy binocular fixation. The determination of the rotations of the eyes by means of the tropometer becomes, then, the second important factor in the investigation of the muscular adjustments of the eyes.

The relationship of the retinal meridians to the meridians of space, the third adjustment in our classification, derives its claim to particular attention not only from the fact that the deviations from the normal are in themselves hindrances to good binocular adjustments, but also because they are the causative forces underlying heterotropic and heterophoric conditions.

Examinations to determine faulty relationship of the visual axes are now of fairly common occurrence. Tropometric examinations are made by a few of the more careful observers. But the determination of the direction of the retinal meridians seems to have been neglected to such an extent that it is exceedingly rare to find the report of a case in which this relationship has been recorded. It is therefore fair to assume that it is not investigated and that this important factor in the function of vision is not generally understood. Consequently it may be of value to discuss this relationship in some detail.

Departures from the best adjustment of the retinal meridians are designated as *declinations*.

Declinations were defined by Dr. George T. Stevens as "Deviations of the vertical, horizontal, or any given meridian of the eye from the corresponding meridian of external space when the line of regard is directed parallel to the median plane and in the plane of the horizon, the head being exactly erect, or more technically, in the primary position." To state this definition more familiarly, if the head is erect and the eyes are directed straight in front towards the distant horizon, declination would be indicated by a tilting or rotation of the eyeball on the antero-posterior axis.

Just as, in case of heterophoria, parallelism of the visual lines is maintained in spite of the tendency to deviate from

parallelism, so, in the case of declination, under all ordinary conditions the tilting of the eyeball is corrected and the eye held in an erect position. In order to determine the existence of declination, each eye must be disassociated not only from its fellow but also from objects of external space. This can be done most effectively by means of the clinoscope.

This instrument consists of two horizontal tubes mounted on a standard. At one end the tubes are closed with opaque disks which have a pin-point opening in their centers, the distance between these openings being adjustable to the pupillary distance. At the other end are translucent disks on which may be drawn various stereoscopic diagrams. The distal portions of the tubes are so

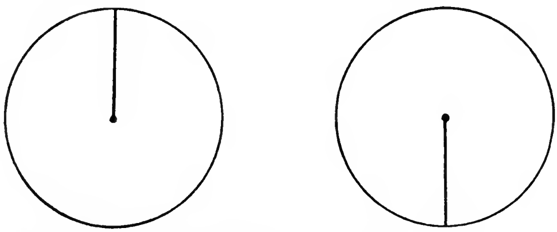

Fig. 1. Test objects for the determination of declination

arranged that they may be rotated on their antero-posterior axes, thus permitting the translucent disks to move through various angles which are indicated on the outside by a pointer in contact with a scale marked in degrees. There is also a level to assure the proper position of the tubes and a device at the near end to maintain the head in an erect position. The perfected instrument has other adjustments which are valuable for laboratory use but not essential for ordinary clinical purposes.

The test objects best adapted to the determination of declination are two vertical radii, one disk containing a radius from the center to the upper circumference, the other a radius to the lower circumference, as shown in the accompanying diagram (Fig. 1).

The observer, looking through the pin-point openings, quickly learns to unite the two circular disks into one. The two central dots unite to form one center with an upward and a downward radius. It is then the part of the examiner to rotate both disks back and forth until the two radii seem to the observer to be upright so that there is apparently a single vertical diameter, the radii forming a continuous straight line. In practice it is not always possible for the observer to unite the two disks accurately and there may be a slight interval between the two centers. In this case the two radii should be so adjusted that they appear vertical and parallel, or the observer may be assisted in uniting the images by the use of a prism before the eye-piece which, if it is of low degree, will not materially alter the result of the examination. A vertically placed prism is often necessary in cases of hyperphoria.

It is evident that under these conditions the two test lines of the clinoscope will be placed in positions which will correspond with the outward projection of the vertical meridians of the observer's retinae. If the test lines lean away from the true vertical of external space, indicated by the zero mark on the scale, the amount of the leaning is indicated in degrees by the pointer on the scale. A leaning toward the temple is designated as plus declination and a leaning nasalwards as minus declination.

Examinations with this instrument, conducted as part of the routine investigation of every case tested functionally, have led to the inevitable conclusion that declination is a very common anomaly. It is met with in every combination of leanings for the two eyes. That is, the declination may be positive or negative in both eyes, positive in one and negative in the other, of equal or unequal degree, and one eye may show no declination while the other shows a considerable degree of leaning.

There can be no question but that the relationship of declination to heterophoria and heterotropia is that of

cause and effect. While declination may, in many cases, be found without deviation of the visual lines or a tendency to deviate, still it is always present in heterotropia and heterophoria. Thus as a general rule it will be found that with exophoria positive declination of an equal amount will be found in each eye; a positive declination in one eye with an equal amount of negative declination in the other is usually associated with esophoria; while unequal leanings of the meridians frequently result in hyperphoria.

An analysis of a single case, that of equal positive leanings of the two eyes, will indicate the mechanical principles involved. Under these conditions, in order to maintain binocular fusion, both eyes must be rotated nasalwards on their antero-posterior axes so that the retinal meridians may correspond with the meridians of external space. The muscles which will accomplish this most effectively are the superior obliques. But these muscles are also abductors. When, therefore, they are called into action under the stated conditions, they will not only erect the vertical meridians of the two retinae, but will also have a decided tendency to cause the visual lines to diverge and thus produce an exophoria.

The analysis of the mechanism of esophoria and hyperphoria is somewhat more complicated but none the less convincing of the relationship of cause and effect between declination and heterophoria.

It will be readily seen that there is no weakness or "insufficiency" involved in this adjustment. It is simply a question of an abnormal demand being made upon the ocular muscles to satisfy the instinctive insistence on binocular fusion. For if the vertical meridians of the retinae, and with them all other meridians, are not held in their proper relation to each other and to the meridians of space, confusion of vision would be the inevitable result. It is also clear why it is that prisms are so frequently ineffective in efforts to correct heterophoric conditions. They do not correct the declination which underlies the heterophoria.

In quite a similar way declination can be shown to be the dominant factor in the causation of heterotropia or squint. In these cases the ordinary clinoscope often fails us and other methods have to be employed to find the relationship of the retinal meridians. A special instrument with short tubes in which the lines of the test objects are magnified by means of convex lenses is often useful. In other cases the screen test is used; a careful observation of the blood vessels near the cornea will reveal the rotation of the eyes on their antero-posterior axes as they move from their position behind the screen when covered to the position of fixation when uncovered.

As has already been stated declination may exist alone without causing any heterophoric manifestations. Many an asthenopic case which has baffled the refractionist could be readily solved if the relationship of the retinal meridians were investigated.

It is not necessary here to discuss the clinical aspects of declination. Naturally they are practically the same as those of heterophoria. There then remains the important question of its proper correction.

It would be possible to construct a complicated optical system which, by means of reflecting prisms, would correct this condition. Such an apparatus would, however, be decidedly impractical.

The only available method, then, is by means of surgical interference. Such operations should not have as their object either the shortening or lengthening of any of the ocular muscles. Their aim should be to so adjust the insertions of certain tendons that the muscles may have a new point of traction and in this way produce an actual rotation of the eyeball on its antero-posterior axis. Under the hands of a skillful operator the declination may be corrected, heterophoria if present will disappear, and highly satisfactory clinical results may be confidently expected.

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Einstein and Optics

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EINSTEIN'S doctrine of relativity should have a peculiar interest for all whose course of thought or work leads them into contact with the science of applied optics, whether in its mechanical or its physiological phases, not alone because his doctrine is based upon a consideration of the nature and behavior of light (that is a matter of appeal to the physicist rather than to the optician), but because it has its development in the laws and phenomena of image-formation. The very essence of Einstein's position consists in the fact—always well recognized by physiologic opticists, of course, but never before made the premise of physico-astronomical calculations—that man lives his life in the image-space of a lens system.

From the earliest time that man began to make observations of the universe surrounding him, he has been obsessed with the dual conception of a subjective and an objective world, and has attempted to differentiate between what the philosopher calls phenomena and things-in-themselves. This dual conception still holds the intellectual field. The conviction still prevails that there is an objective universe, which exercises a causal, or at all events a reciprocal, relation with the subjective content of the mind. Every sane scientist and philosopher believes that there do exist certain objective entities, or "things-in-themselves," which, through the medium of various physical energies and transmutation processes—of which light and vision furnish a conspicuous example—arouse in consciousness certain reactions which may be regarded as their subjective analogues; that these analogues constitute the phenomena of the subjective universe; and that there is a definite, characteristic, constant reciprocal correspondence between the objects and their subjective analogues. This much may be conceded, at least as a highly probable working

hypothesis, without violating any of our scientific intuitions.

It has been the habit of philosophers and scientists, in common with the man in the street, to regard the objective factors of the universe, the "things-in-themselves," as being real, in the sense of having physical properties susceptible of demonstration and mensuration, in contradistinction to the unreality of subjective phenomena, and to consider that to them alone the computing tools and methods of science were applicable. Subjective phenomena, according to this conception, have no dimensions or weight or temperature, and therefore cannot be made the premises for any material or mathematical definition. Nothing constant or reliable can be predicated upon them.

Einstein's doctrine rests upon precisely the opposite assumption. But that is not all; nor is it the most significant feature. His reasoning points to the truth, which seems to have been peculiarly unconsidered, that, so far as light and vision at least are concerned (and the same truth will doubtless be found to hold good for all sense phenomena), things-in-themselves do not even form the real and immediate basis for those reactions in consciousness which constitute subjective phenomena. The energized media undergo certain transmutations, involving alterations in their physical qualities and spacial relations, before they reach the subjective threshold, and present to the senses a group of phenomena—whether we must call them objective or not remains to be determined—which have no identity with the objects, and give no constant or definite information concerning them. It is to these intermediate phenomena, as a matter of fact, that we apply our methods of mensuration, and it is these, if anything, which constitute, so far as we are concerned, the real universe.

In the case of vision, it is not objects that we see, but images. So obvious is this that it seems like a superfluous truism to state it. But the inevitable corollary of this truth is that it is not objects that we define and measure,

but images; and while that may be equally a truism, it is a truism which has never hitherto been properly evaluated and applied until Einstein taught us to evaluate and apply it. He illustrates the point by a homely instance. If a rod be held horizontally before the eyes, in the vertical plane, it appears to be of a certain length, and the application of a yardstick in the same plane registers that length in centimeters. If the rod be now swung around a little in the horizontal plane, it appears to be shortened, and the yardstick (held as before) registers less centimeters. We say that the rod itself has not changed; only our view of it has shifted. But, as a matter of fact, in our universe there is no "rod itself," only an image. Try as we will, we cannot possibly apply our measuration to the rod itself, but only to the image; and the image *is actually shorter.* The image of the yardstick is all we have to gauge it by, and if that be kept constant, the length of the rod, so gauged, is actually less. If the yardstick be similarly moved, its image, which is all we know of the yardstick, will also become shorter and the image of the rod will again coincide with it.

Another illustration used by Einstein is that of a stone dropped from a moving train. To the person on the train, who drops it, the stone describes a straight projectory to the ground; to one who stands on the track as the train goes by, the stone describes a curved projectory. Now, it is clearly impossible that there can be two objective trajectories, occupying, or rather traversing, two different portions of space at the same time. The truth is that we know nothing whatever about the real projectory; each sees an image of the trajectory, which actually is exactly as he sees it. Systems of measurement can be applied only tc the images, and can define them alone.

The significance of all this is that, as previously stated, man lives his life in the image-space of a lens. Of the object-space and its phenomena he knows, of his own

experience, nothing. True, his objective experiments and observations of object and image relations enables him to make some fairly approximate deductions concerning that unknown space on the object side of the lens. Probably not nearly so accurate as he imagines, since these observations, too, are carried on by means of images in his image-space. But that is beside the mark.

It is not the intent of this little preachment to follow the intricacies of the Einstein doctrine. Einstein is said to have asserted that there are only ten men in the world capable of following his theory to its conclusion; and the writer does not regard himself as one of the ten. He does not even understand the mathematical language which Einstein speaks. He has, with considerable labor, dug his way through as much of it as his limitations permit—principally its philosophical phases—and does not feel by any means competent to expound even so much of it to others. All that is here attempted is to point out the intimate interest that the doctrine has for the mechanical and physiologic opticist.

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Editorials

The Dominant or Sighting Eye

THERE seems to be a boss, a dominant element or a controlling factor to everything in life. In rare instances are two sets of circumstances, two personalities or combinations of circumstances and personalities such that there is not a very definite controlling or dominant "something" present. Each of us is said to be of dual nature in all ways—mentally, morally and physically—but one of these natures is in each particular the dominant one. To be sure we are creatures of habit. But the great question is: Do we form the habits or do the habits form us? Most of us are right-handed; therefore, the right hand is the boss hand or the controlling influence in all actions in which these members are involved. As a result, I suppose, each of us gets into his overcoat or laces his shoes or does a hundred and one trivial things entirely different than he would if the other hand and arm were the better serving or surer or quicker responding members. And then again, perhaps a few of us are ambi-dextrous. Most of us left to ourselves to wander about will travel in a circle: evidently there is a boss foot and leg. And so on—there is no doubt about the fact that each of us is a physical organization bossed and dominated in every act by just one-half of a self.

And the eyes are no exception. There is nearly always a dominating or sighting eye. One would be tempted to guess offhand that the condition of right- or left-handedness would determine the condition of supremacy of the right or left eye as the directing eye. We should expect that those who write and work toward the right side of the body would have binocular vision in which the right eye would be the directing or sighting eye and that the left

eye would be forced to turn in such a manner as to unite with the dominant eye in its functions of seeing. This is doubtless quite commonly the case and yet instances will be found in which the left eye is the directing eye in cases of right-handedness and again some cases in which each of the two eyes appears to be an equal master.

In the course of some casual observations and some simple tests over a period of years the writer has found quite a number of cases of men who, for example, were decidedly right-handed and whose right eye was the directing or sighting eye and yet those men could not bat a baseball or play golf unless they played left-handedly, indicating that certain visual requirements were paramount and had to be satisfied even at the expense of the apparently well developed tendency to right-handedness.

And this matter of the directing or dominant eye is not one which is purely of academic interest and of no practical importance. In the first place, nearly all of our textbooks and writings and all of our explanations of the physiological and optical phenomena of binocular vision, as well as our clinical tests upon the elements of convergence, fusion powers and muscular insufficiencies, are based upon the principle of triangulation, in which the line joining the nodal points of the two eyes—or interpupillary distance—serves as the base of the triangle, while the point of fixation is made to lie on a line drawn as a perpendicular bisector to the base line, so that the distances from the nodal point of each eye respectively to any point on the median line are equal. Binocular single vision is thus graphically diagrammed and discussed as though each of the two eyes was equally dominating and directing and that as a result the most accurate fixation for ease, comfort, and proper location in space of any object would occur if the object fixed was located on the median line perpendicular to the ocular base line, so that equal amounts of accommodation and equal amounts of actual turning in, or convergence, of each eye

would be involved. In the bulk of cases, however, no such ideally simple arrangement exists and equal division of labor is probably not present. In cases of right-eye dominance and right-handedness simple test will show that, in the majority of cases, the object fixed is definitely located and sighted by the right eye and that the visual triangle insofar as binocular single vision is concerned is a right-angled triangle with the right angle subtended at the nodal point of the right eye.

If the premise as set forth above is correct, namely: that in the majority of individuals one eye is the dominant eye and the other is simply the "follower-up," then it would appear that in such cases each of the two eyes has a distinct function to perform in the act of binocular single vision. For example, the right eye is the fixating or directing eye and the object looked at is sighted by the right eye in its own line of vision. The left eye then has to converge or turn in until binocular single vision occurs and it is the non-fixating or non-directing eye which is the eye which must carry on the function of *actual* motion in the act of convergence. It is this eye, therefore, which we believe furnishes us the information relative to the location in space of the object, *i. e.*, as to its distance. In other words, we have reason to believe that in cases in which a dominant or directing eye exists—and our experience has given us the approximate estimate that this is so in 95 pairs out of every 100 pairs of eyes—the *dominant eye* is the eye which sights or *fixates* the object and, all other things being equal, involuntarily acts through the function of accommodation to the end that the object is seen as distinctly as possible: the *non-fixating* or non-sighting eye, on the other hand, is not primarily involved at all in sighting or in initially endeavoring to see distinctly, but it is the *moving* eye and so converges as to give binocular single vision and hence fulfills its function of estimation of distance and actual location of the object in space.

A few men have written, some have taught and a small number have practised in their work in ocular refraction the following simple rules:

1 Do not blur, fog or do anything which will leave the visual acuity of the dominant eye lower than that of the non-dominant eye. We can best illustrate this by a simple case. O. D. sighting eye. O. D. +1.00 D. S., O. S. +1.00 D. S. If under test as to the equality of vision it is found that the acuity of the right eye is slightly better than the left, we may either leave matters as they are or else exactly balance the acuity of the eyes. But if the acuity of the non-dominant or non-sighting eye (left) should be greater than that of right, then experience has seemed to indicate that discomfort will ensue and persist for considerable periods of time unless the condition of equality of acuity is established or better still, slight preference given to the sighting eye.

2 If prismatic corrections are incorporated in glasses prescribed, do not incorporate prisms in the lens worn before the dominant or sighting eye. In squint, we commonly find that one eye becomes dominant and the vision in the other eye is suppressed. If any attempts should be made to restore binocular single vision and prisms should be prescribed, it seems logical to say that they should be placed *in toto* before the squinting eye. In cases of hyperphoria in which, in general, a prism may be given base up before one eye or down before the other or divided between the two eyes, it seems to be desirable in cases of low prismatic assistance to incorporate the whole of the prismatic element in the lens worn before the non-sighting eye. In other words, it seems a wise procedure, when possible, to do nothing which will in any way interfere with the directing eye in its function of true sighting.

From the remarks which have been made in the foregoing paragraphs it would appear that there are good theoretical and experimental grounds for believing that these two dicta

of experience are fairly sound and worthy of further consideration and experimentation.

Having pointed out the significance of the dominant or sighting eye in the ordinary acts of vision and the localization of objects in space in the case of every individual pair of eyes and having briefly presented reasons why the actual determination of the dominant eye may be of sufficient importance to make it a matter of test as a part of the routine examination of each and every pair of eyes, it remains to describe and discuss some simple tests which will quickly give us the information as to which is the sighting eye. The writer has for years employed the following easy test: Let some familiar object, as the *vertical* edge of a door, window, a picture or such a common object as a tree viewed from the examination room, be chosen as the object to be sighted. The person under test is requested to raise the arm into a vertical position and, to "line up" the approximately vertically held index finger, both eyes being kept open and employed in the act of vision. When the person under test states that the alignment has been made, the examiner may then readily locate the position of the finger with reference to the eyes and record the sighting eye as right, left or neither. To obviate the possibility of right- and left-handedness entering into the test, repetition of the test is to be made with the other arm and index finger as the member to be lined up with the object looked at. Or the test may be conducted in this manner: After the person under test reports a satisfactory alignment, the request may be made that, without disturbing the position of the aligned finger, each eye be closed in turn and a report of the phenomena as to apparent "jumping" of the finger or decided failure to alignment when the non-sighting eye is open and its mate is closed. To illustrate, the writer's right eye is the dominant or sighting eye. Aligning a finger of either hand with a vertical object such as the corner of a room, holding the finger fixed in position and then alternately

closing each eye, he observes that, with the right eye open and left closed, there is still perfect alignment, but when the right eye is closed and the left opened, the finger seems to have been displaced laterally toward the side of the right eye and is distinctly out of alignment.

A few years ago Dolman, while working in the Medical Research Laboratories at Mineola, L. I., took up the matter of tests for determining the sighting eye. He objected to some of these simple tests, saying that they did not meet the exact requirements of research work. The possible coördination between the sighting eye and right- or left-handedness is a possible source of error; hence he concluded that tests made by pointing with either forefinger or with a pencil in either hand or by sighting through a ring held in either hand are open to criticism. Dolman concluded that the possible influence of either hand would be greatly reduced by holding the test object in both hands. A thirteen by twenty centimeter card with a three centimeter round hole in the center was used instead of the customary finger or pencil. The use of such a card forces the selection of one or the other eye for sighting through the hole. The test is made by having the person under test take the card in both hands and raise it slowly at arm's length while looking fixedly at a spot of light twenty feet away. Both eyes are to be kept open and the light is to be located through the hole. The eye selected for this purpose is the sighting eye. The test is both simple and convenient, prevents negative results and uncertainties and lessens the possibility of the influence of the right or left hand on the test.

The Spherical and Chromatic Aberrations of a Lens

PROFESSORS Ames and Proctor of Dartmouth College contribute in this issue a paper on some of their work upon the spherical and chromatic aberrations of the eye. In their paper brief references are made to some of the classical experiments made by earlier experimenters in this portion of the field of physiological optics. In order to serve in a way as an introduction to their essay and to add a further background of description to their work, a résumé of some fundamental notions and investigations on these topics seems appropriate.

A caustic is formed by the refraction of rays of light passing, through a wide aperture, from one medium to another whenever the refraction takes place at a curved surface. If air and glass are the media and rays of parallel light are passed from air into a piece of glass having a surface convex toward the incident light it will be found that rays refracted near the pole cut the axis and each other approximately at a point. On the other hand, rays refracted at the surface remote from the pole cut the axis at points nearer the surface than the focal point for the central beam. The more remote the point of incidence the nearer the point at which the refracted rays cut the axis. This phenomenon is known as *spherical aberration.* Rays refracted at neighboring points of the surface somewhat remote from the pole intersect each other before reaching the axis. Each point of intersection is a sort of focal point; the curve joining them is called the caustic curve. A parallel pencil of light incident at some distance from the pole will give rise to an astigmatic pencil passing through two lines respectively perpendicular to each other. These lines are known as the first and second focal lines or the tangential and radial lines. Somewhere between these two lines the section of the refracted pencil is approximately circular and is known as the circle of least confusion. Hence, when the aperture is not very small

the rays do not, after refraction, meet at a point, for the peripheral portions are more refracted than the central ones. The degree of aberration increases as the square of the aperture and as the cube of its refracting power. It likewise depends upon the distance of the object and the form of the lens. If, for example, a lens having a central power of +20D. is taken and examined for spherical aberration at a point 15 mm. from the lenticular center it will be found that the power of the lens exhibited at this distance depends upon the form of the lens somewhat as follows:—plano-convex with the convex surface in front, 22.3D.; biconvex, 23.6D. and plano-convex, with the plano side toward the incident light, 23.8D.

These phenomena may be tested out by anyone possessing a few lenses and a little patience. Let a +16D. or +20D. lens be taken and suitably supported, and let the lens be illuminated with a broad source of light placed at a considerable distance from it. Let the lens be covered with an opaque screen containing four small apertures: two of these should be nearer the center of the lens and two situated at the peripheral region of the lens. Using a suitable receiving screen, positions can be found in which four images will be obtained, the two central ones circular and the two outer ones elliptical in shape and *vertical* in position. As the screen is drawn toward the lens the two central images may be made to coincide. Advancing the screen still closer to the lens a position will be found in which the peripheral region images will blend. Passing on still closer to the lens the peripheral spots will become elongated in the *horizontal* direction, and the positions of the images will be found to be in juxtaposition with the apertures giving rise to them. A simple testing of these phenomena will add considerably to the clarity of the discussion on this subject presented in the Ames and Proctor article.

Volkmann used this method for the determination of the spherical aberration of the eye. He used four openings

before the eye and looked at a pin placed beyond the punctum remotum and observed in a general way the phenomena discussed. Thomas Young employed fundamentally the same method using his optometer carrying a +10D. lens, a vertical slide carrying slits—two or four in number—and a horizontal rule carrying a white line on a black back-ground. By means of differently spaced slits in the vertical rule of the optometer it is possible for an experienced observer to measure the spherical aberrations of various zones of the eye and to find for his own eye the far-point of the central and of the peripheral parts.

Tscherning constructed a simple instrument known as the aberroscope, consisting of a plano-convex lens the plano side of which is cut with a mesh of small squares. A small luminous source is viewed through the lens held at 10 to 20 centimeters from the eye and observations made upon the character of the lines seen, *i. e.* whether curved or not and the direction of curvature. This method is wholly qualitative in character.

The spherical aberration of a lens, therefore, finds its counterpart in the human eye and has to do with distortion, unequal magnification and curvatures of the images.

The aberrations of a lens arise from the consideration that every lens is fundamentally a composite prism and every prism has an angle of refraction, an angle of deviation, a resolving power and a dispersive power. This last property is its ability to produce from composite light a spectrum or analysis of its constituent parts. A lens, therefore, if one considers the central portion only, causes a series of colored images or points to be formed on the axis, the blue end of the spectrum being nearer the lens. The phenomenon of chromatic aberration of lenses is easily illustrated. Using sunlight, for example, and a white cardboard screen upon which the images formed by the lens may be received, the focus of nearest white light can be found.

If the card is moved inside of this point a blurred image will be received but the center will be blue surrounded by a red halo; if the screen is placed beyond the yellow circle the reverse of the above phenomena will be seen. The cobalt glass test is based upon these phenomena. If a distant light source is viewed through this glass, which transmits only the extreme portions of the spectrum, and the eye is emmetropic one composite color effect only will be noticed. If the eye is hyperopic, the far-point is back of the retina and a blue center surrounded by a red halo will be seen. If the eye is myopic, just the reverse positions of the color areas will exist.

Young made the first estimates upon the chromatic aberration of the eye, while Fraunhofer made the first reliable measurements on the difference in the focal lengths of the eye for extreme spectral colors. He observed a prismatic spectrum through an achromatic telescope the eye-piece of which carried a cross-hair. Fraunhofer noticed that he had to move the ocular nearer the cross-hairs for clear vision when observing the violet portions in contradistinction to the red regions. By fixing an external point with one eye he so adjusted the eye-piece as to give equal distinctness of the cross-hair and object in two spectral regions. The optical constants of the eye-piece being known, the corresponding visual distances could be found. He discovered from his work that an unaccommodated eye which sees an object of color corresponding to the spectral line C (between orange and red) cannot see this object clearly in light of wave-length corresponding to the line G (between green and blue) unless it is some 18 to 24 inches nearer the eye. Helmholtz varied the experiment somewhat and used monochromatic light, passing it through a very small hole in a screen; he then found the greatest distance at which the opening maintained its original pin-point form. The greatest visual distance in red light was 8 feet, in violet 1.5 feet and in the extreme violet close to the ultra-violet about 1 foot. These data

show that Fraunhofer found about 1.5 to 3D. and Helmholtz 1.8 D. as the chromatic aberration of the eye.

These aberrations in the human eye are not defects which ordinarily need correction. But they exist in every eye and the outer world as it is appreciated by the human mind is seen through the images received at the retinae. The reproduction of things as they are seen by the eye of the artist and hence the whole technique of art as a representation of "things as they really are"—irrespective of what Professor Einstein has to say as to our never seeing "things" but only images—must be based upon scientific experimentation of the character undertaken by Profs. Ames and Proctor.

Prescribing Prisms in Ocular Practice

David Kletzky, D. O. S.

THE efficacy of the prism in position of rest; the causative factors of heterophoria; the tests in vogue for the detection of heterophoria, and the logical solution consequential to the treatment of this apparently secretive and evasive anomaly, have been and still are under the influence of much controversial discussion.

The writer, fortunately having had an experience of over twenty-five years in the investigation of the extra-ocular muscle status, with abundantly good results in the treatment of *true* heterophoria by the application of the prism in position of rest, is firmly convinced that nothing will put an end to the much disputed questions, stated in the first paragraph, but the addition of a chapter on *spastic heterophoria* to the fund of knowledge we now possess upon the subject.

The writer's extensive experience in this field, likewise, leads him to make the following statements; and subsequently he will seek to establish the foundation for their belief:

(1) That *true* heterophoria is an anomaly the seat of which is chiefly found in the synergic contractile power of all the extra-ocular muscles in the act of binocular and direct visual fixation. In other words, it lies in the function of coördinating the two eyes for direct vision.

(2) *True* heterophoria, as investigations show, has no relation to and therefore is not found in the function of the associate rotational movements of the eyeballs, as in the act of directing the eyes to the right, left, up or down. Anomalies of the associate rotational movements are *in toto* ideopathic in character, the seat of which is either found, in an extreme degree, in any of the extra-ocular muscles or in paralytic nerve action. Therefore, it matters

not what manifest degree of true heterophoria we may find, in a given case, under any of the dissociation tests; such a case will always show normal, even though forced, associate binocular rotational movements in all the cardinal directions.

(3) Orthophoria, as disclosed by the application of the different dissociation tests in vogue may, and often does, hide a grave *spastic* heterophoria of considerable degree, the disclosure of which requires diagnostic finesse and tests greatly at variance with the ordinary dissociation tests and their diagnostic implications. This therefore means that, unless the examiner is masterfully prepared to differentiate between an apparent orthophoria which is real, and a likewise showing of an orthophoria which is spastic and, therefore, spurious, error in diagnosis with resultant eventual dissatisfaction is the inevitable outcome.

(4) The disclosure of one kind of an heterophoric tendency, as it casually shows up by any of the dissociation tests ordinarily applied may, under a finer and more precise method of diagnosis, to be disclosed later in the text, prove to be an heterophoric tendency of a different nature, *i. e.*, an apparent esophoria may reflexly show up as the result of two chief causes: (A), an excited or spastic ciliary muscle activity, or (B), a spastic hyperphoria; (A) and (B) may coexist in the same case.

(5) Manifest hyperphoria, excessive in degree, either causes to show with it a spurious exophoria in the distance test, and little, if any, in the near, or it exaggerates a true exophoria which may coexist with the true manifest hyperphoria.

(6) The internal recti, the superior recti, and the inferior recti have in them an aptitude to spastically over-act; and thus, under any of the dissociation tests, may show a right hyperphoria, whereas the true condition is a left hyperphoria, when the superior rectus of the right or the inferior rectus of the left over-act; an orthophoria or a slight

esophoria, when the true condition is exophoric, when the internal recti spastically over-act.

(7) There is no aptitude in the external recti to *spastically* over-act, i. e., showing, under any of the dissociation tests, a spurious exophoria because the external recti over-contract, spastically, and pull the eyes outward. Such an aptitude is not inherent in the external recti.

(8) Apparent esophoria in the distance and near tests should always be treated as reflex, and is therefore spurious. Prisms with their bases toward the externi muscles, prescribed in position of rest, are never indicated or beneficial in the treatment of esophoria.

(9) Prism-adduction in the distance has no value as a diagnostic measure, and is therefore a useless procedure.

(10) Prism-adduction in the near is of much value in diagnosis when the center of fusion with the reserve power of convergence is in question.

(11) Prism-abduction in the distance is of much value in diagnosis, because this is the only test we have which enables us to approximately record the negative power of convergence.

(12) Prism-abduction in the near is of no value in diagnosis, and is therefore a useless procedure.

(13) Prism-sursum and deorsumduction in the distance is of much value in diagnosis, when rightly applied and properly interpreted.

(14) The proper application, significance and just interpretation of all the prism-duction tests are of greater value in bringing out the true status of the coördinate function of the extra-ocular muscles than is possessed by the various dissociation tests in vogue.

(15) To successfully cope with the function of ocular coördination, the examiner must be imbued with a certain sense of delicacy of observation and unremitted guardedness. Haste and haphazardness in the investigation of

the function of binocular visual fixation should find no place in the undertaking of this very interesting but delicate task.

(16) The prism, in position of rest, when intelligently prescribed, is a very practical ameliorative agent in all *true* heterophoric cases which complain of disagreeable or painful symptoms.

(17) Normally synergised extra-ocular muscles cannot and will not tolerate prisms in position of rest, for vision requiring prolonged and direct visual fixation.

(18) An abnormally synergised extra-ocular muscle is greatly favored by the application of the prism, in position of rest, only to that extent which the degree of deficient innervation calls for, and will not tolerate a prism which overcorrects the innervational deficiency; therefore, the full measure of the heterophoric deficiency is found only in that power prism which just fully corrects, but not overcorrects —the *modus operandi* of such a correction will be given in the text.

(19) Normally synergised superior or inferior recti will not tolerate even so little as one-half dioptry prism with its base up, or down, before either eye of an hypersensitive patient.

(20) Normally synergised external or internal recti are not perceptibly affected by a prism power up to one prism dioptry, with its base in or out. Any greater amount becomes intolerable to the sensitive patient.

(21) In true hyperphoria, the amount of prism-dioptries which may be tolerated, in position of rest, with much comfort, was found to reach as high as twelve, *i. e.*, six prism-dioptries for each eye.

(22) In exophoria, fourteen prism-dioptries, *i. e.*, seven prism-dioptries for each eye, in position of rest, were found to be quite tolerable and comfortable.

(23) The metamorphopsia, or distortion of objects, caused by prisms of high degree is of little consequence, is only slightly noticed by the patient, and entirely disap-

pears while the heterophoric tendency is being made receptive to the high power prisms, by a procedure we shall make plain in the text.

(24) The extra-ocular muscles are *not* weakened, when subjected to a correction of prisms in position of rest, but, contrary to that, are vitalized thereby—as we shall subsequently aim to establish.

I

SPASTIC HETEROPHORIA

The writer (vide *The American Journal of Physiological Optics*, October 1920), emphatically stated as his firm belief that: "*The basis for comfortable, enduring and undisturbed binocular single vision is found only in an undisturbed innervational synergism of physiologically related functions of the binocular visual sense organs.*" If we are to expect such a state, the following physical, anatomical and physiological entities must obtain:

(1) Since the visual organs are "the flesh of our flesh," there must first and foremost prevail a body economy in which the innervational expenditure is commensurate with the innervational income; in short, a healthy body.

(2) Symmetry in anatomical construction of the ocular bulbs with antero-posterior diameters commensurate with properly curved, perfectly aligned and physiologically toned-up refractive components, so that incident parallel rays may focus upon the fovea in the nicest possible degree.

(3) Perfect alignment of the ocular orbits with adequate orbital fascia. An extra-ocular muscle assemblage of natural length, attached to the ocular bulbs in such a manner that the eyes, influenced by the will, may be swung or held taut in the orbits by the aid of a steady, synergic innervational influx as though they were but a single organ, ever ready and unfailing in the performance of the visual act. This is *emmetropia with orthophoria.*

A conception, such as is given above, without any deviations, is possible only in schematic mechanical devices constructed by the hand of man. Not so, however, by the "hand" of Nature. Nature, in providing us with eyeballs, orbits, muscles and the like, does not cast from molds. She is an artist. She never repeats herself. She doesn't produce two things exactly alike. Her plants never grow two pieces of fruit that exactly match. Being a very resourceful artist, she puts only a dab of likeness, so to speak, in everything she creates, and then she lets her other physical forces rule over her material creations. In the case of our visual organs with their muscles, Nature's ruling force is the innervation. Irrespective of *marked* anatomic differences in the extra-ocular muscles, the muscles *will* coördinate the eyes if the innervation does not fail them. Therefore, if the innervation tends to fail but slightly, we have the condition known as *heterophoria*.

The term *heterophoria* presupposes that associate ocular rotational movements are unimpeded; binocular single vision obtains, but is accomplished by undue muscular effort guided by the early acquired psychic fusion sense.

Analysis of the above shows that heterophoric eyes have in them all the normal attributes of orthophoric eyes but with one exception, thus:

In orthophoria we have (A), unimpeded associate rotational movements (B), binocular single vision, (which presupposes a normal fusion sense), accomplished by (C), coördinated muscle effort which is innervationally synergic and, therefore, unstrained. In heterophoria, the exception, therefore, is the function (C), because coördination of both eyes, for the act of binocular single vision, is accomplished by undue, or strained, muscular effort.

In differential diagnosis, *i. e.*, whether a given pair of eyes is orthophoric or heterophoric, the investigation of the function (C) becomes the important factor. Evidently so, because (A) and (B) presupposedly must obtain as normal

attributes before the nature of the function (C) becomes a distinctive factor for investigation. This substantiates the foundation of our premises (1) and (2). The physiologic function (C), which is enacted by all the extra-ocular muscles, in order to so coördinate both eyes that the image of a certain object formed upon the fovea centralis of one eye is in exact positional correspondence with the image of the same object formed upon the fovea centralis of the other eye, is so intimately bound up with the psychic phenomena of the sense of sight that a study of the former compels a close study of the latter. This is obvious because the two are relatively interdependent. Their relationship and consequent interdependence is a gradually acquired one. Its origin may safely be said to date from the time the eyes of the tiny infant are ready to filter the God-given light which pervades all space in this universe. Psychologists aver that the mind, or that part of it which takes cognizance of sight sensations is, in the new-born infant, a blank.

That there is no coördination of the eyes of the new-born infant we can see by observation. By observation, also, we learn that in the new-born infant the sense which pertains to the perception of sight impressions is, primarily, one gradually acquired. It is through the gradual acquisition of the primary sight impressions that the coordinate function of both eyes is established for the chief purpose of psychically fusing or blending the two visual impressions as they are focused on correspondingly minute positions of each retina.

The writer holds strongly to the belief that while convergence of the visual axes *per se* is a distinct physiologic function, it is, nevertheless, a psychic impulse governed by the same center which dominates the impulse for coordinate parallel visual fixation—as in the act of looking at an infinite distance. We shall substantiate this by the fact that while convergence is accomplished by the rhythmic contraction of the two internal recti, notwithstanding, co-

ordination of the two eyes is maintained by the rest of the extra-ocular muscles under normal innervation, even though the act of convergence complicates matters in a way different than the act of simply coördinating the eyes when the gaze is directed at infinity. To be more explicit, we shall state that at the moment the impulse to converge is excited, the rest of the muscles not directly concerned in the act must, in a rhythmic sort of way, slightly but gradually repress *part* of their tonicity in order that the eyes obtain full freedom in their rotation inward. This impulse, that is to say, the act of repressing *part* of the unconcerned muscle activity in the act of convergence, comes from the same psychic center which governs coördination, but is a *negative* expression of the impulse. An exaggerated form of this negative impulse is shown when we learn to willingly relax our eyes while looking upon a near object and heteronymous diplopia therefrom results. It is said that this coördination impulse becomes nil during sleep. It is a fact that most all the tests now in vogue for the purpose of revealing heterophoria have their value in the amount of influence they can bring about in negativing the psychic impulse of coördination.

As a further step in the progress of the psychic visual activities, the ciliary muscles receive their correlated innervational impulse for the distinct function of accommodating the eyes for approaching objects in the line of the infant's sight.

While the psychic impulse of accommodating the eye, in order to conjugate the image and object in regards to their respective distances, has for its excitation a separate and distinct center from that of convergence, as it is well known, we however believe that from the period the function of convergence is fully established, it (convergence) becomes the ruling and enticing force over the impulse of accommodation.

Our reasons for the above belief are borne out by the following:

(1) In considering the complex nature of the visual function, binocularly, we are confronted with two distinct psychic visual impulses. The first, the impulse of binocular single vision. The second, the impulse of sharply focussing the images formed by the refractive media upon the retinae. The first impulse, *i. e.*, the impulse of binocular single vision, includes the function of holding the visual axes in a state of parallelism with that of the function of converging the visual axes for approaching objects. While the second impulse, *i. e.*, the impulse of sharply focussing the images (the function of accommodation) is, as we shall make note, less complex, of minor importance in the *early* acquisition of the psychic visual sense, and is, therefore, a visual attribute acquired as a secondary step, in the progress of the psychic visual activities, to that of the function of coördinating the eyes for binocular single vision. In other words, we hold that the mind of the newborn infant first learns to coördinate and converge both eyes for the act of binocular image blending. This accomplished, as a primary function, the infant's mind gradually begets the desire for sharper definition of the thing or object looked upon binocularly. Thus the function of accommodation thereby assumes its correlative aspect as a secondary function with that of the already firstly acquired function of convergence.

(2) Another reason why we hold that the act of coordinating and converging the eyes is one primarily acquired, is this: The impulse for binocular single vision must be, and certainly is, stronger than the impulse for sharpness of outline of objects. This becomes obvious when we consider the fact that to be annoyed by "double" vision is a greater affliction than viewing objects which are blurred for us in some measurable degree.

We have touched somewhat upon the psychic phenomena of the sense of sight in order to show that the physiologic function (C), as given above, is characteristically sub-

servient to the power of the *will*—the same power that urges *all* our physical activities.

If we consider the important fact that no bodily organ can functionate properly, or with any great degree of endurance, unless (1), the anatomic aspect of such an organ approximates an accepted standard of form, and (2), the functioning organ must be in command of an innervational influx much greater than is demanded for its required function; in other words, sufficient reserve energy. We can see that in the case of any group of the extra-ocular muscles not having enough reserve energy, from some source or other, must functionate, in the act of coördination, under a state of nervous excitation. Nervous excitation, being considered a sequent of a depleted innervational reserve, causes, because of the strong desire of the mind for binocular single vision, the extra-ocular muscles to functionate and coördinate the eyes under a state of cramp or spasm.

The most careful investigators concede that heterophoria may, and often does, exist in a latent state. Exactly like latent hyperopia, being recognized as a spastic condition, latent heterophoria must likewise be considered as a spastic state. Both entities, *i. e.*, the accommodative function and the binocular coördination function, are subject to the instinctive impulses of the *will.* The first, to the instinctive impulse for sharp vision; the second, to the instinctive impulse for binocular single vision. This substantiates our premises (3), (4), and (5).

The writer as he investigates the status of binocular coördination does so from the standpoint that, more often than not, the extra-ocular muscles lack, in a marked degree, the fine standards of fractional millimetric measurements anatomists have set for them in respect to their length, thickness, width and, lastly, their insertional status to the ocular bulbs. Such presupposed fine, fractionally measured anatomic standards if generally accepted, in respect to living organs, would be quite equal to entertaining the

false conception that all natural creations, in the order to which they belong, are cast from the same mold—measuring, weighing and looking all alike.

II

The etiology of true heterophoria, according to the writer's reasoning, may therefore be stated as being due to, first, inherent differences in anatomic construction or in the bulbar insertional alignment of any of the extra-ocular muscles; and second, to innervational deficiencies. Both conditions, as we shall make clear, always exist in latent or spastic *true* heterophoria. In manifest *true* heterophoria. as we shall likewise make clear, the inherent anatomic muscular deficiency alone is often the cause; the innervational influx is, in such cases, abundant.

As we arrive at a closer understanding of the contributory causes which bring about in one class of cases the condition known as manifest heterophoria, and in another class of cases the condition designated as latent or spastic heterophoria, we shall then be able to satisfactorily treat and ameliorate the ill effects of either class of heterophoria.

The writer's extensive experience in observation of the different classes of heterophoric cases leads him to the strong belief that individual idiosyncrasy or temperament is the *sine qua non* upon which depends whether an inherent heterophoria shows up in its true manifest form, under the different dissociation tests, or it is held latent or spastic under the same tests.

As a general rule we come in contact with two characteristically distinct types of individuals who seek our services because of eyestrain symptoms. One type we may classify, temperamentally, and characterize by a term, the writer takes the liberty to designate, *Spasticotonics;* the other type, a term likewise originated by the writer, *Orthotonics.*

The spasticotonic type, be the subject male, female, young or of adolescent age, may readily be recognized temperamentally by the patient's exhibition of great intolerance to the slightest discomfort of bodily feeling. In short, we have in mind the high-strung, emotional, resistless and rebellious nature—the individual who "feels all nerves" but really experiences the feeling of a lack of nerves. While such individuals are being examined, ocularly, they show a spirit of restlessness; they do not or cannot sit straight; they try to touch and often do touch and disarrange the position of the trial frame before the eyes. Under skiametry they exhibit great sensitiveness to the skiascopic light; they cramp up the orbicularis and levator muscles; the pupils, without cycloplegic aid, intermittently dilate and contract; the regularly applied short duration form cycloplegic does not give the full effect in most of these cases. Under subjective testing of the refraction and ocular balance, they are likewise restless, they make too many head movements; they cramp up all their facial muscles; they are nearly always indecisive in their answers because of the intermittent muscular activity, bodily and ocular, which is always present as a disturbing factor.

The spasticotonic, as a class, is a product of either a total l a c k of emotional t r a i n i n g or of a misdirected emotional training. We find spasticotonics among children of the primary school age; especially the children of those parents who neglect to teach or train their offspring the many ways by which they must control their childish desires and emotions. Spasm of accommodation with simulated myopia is found nearly always in those children whose childish actions and emotions are left unrestrained. Such children acquire myopia during their school life—especially the myopia which is always associated with an intractable esophoria. Out of such children, male or female, come forth the spasticotonic adults.

The spasticotonics use up their nervous energy through mentally misdirected physical effort; their thoughts are unsystematized, hence their actions bring no fruits—therefore the great irritability and nervousness. It is the spasticotonic type who, etiologically speaking, is heterophoric because, first, the extra-ocular muscles are inherently deficient, anatomically and, second, has not enough innervational influence to overcome the muscular deficiency with ease. In such individuals, as a rule, being strong of will power but weak in physical action, the combat which takes place between the ocularly mental and physical functions nearly always brings about cramped, spastic or latent heterophoria —as we choose to call the morbid condition.

Aside from the anomalous ocular spastic coördination it has been our experience to observe that the spasticotonic patient quite regularly shows transitory, material changes in the refractive constance; especially in the amount of already earlier recorded astigmatic errors accompanied with many changes in position of the meridian axis. Pseudo astigmia is quite common in such cases; and, very often, an inherent true astigmia is totally masked because of the spastic binocular coördination.

The *orthotonic* type of individual is the antithesis of the spasticotonic type. In the orthotonic child we observe an attentive, well behaved, trustful and very patient little subject. In a word, the orthotonic child, especially that of school age, shows the good effect of an earnestly governed training of the childish emotions by those under its care. Out of such children spring forth that regretfully small percentage of mentally well-balanced adults of our boastful civilization. We have in mind the characters of that class of humanity which, fortunately or circumstantially having been properly guided and trained from the earliest period of their lives, is truly the backbone of our social order. These we may find in all social walks of life. We find such types among the partially literate but religiously inculcated

fathers and mothers of the common labor class; the well-fitted, satisfied and industrious mechanic; the mature, well-trained, easy-going, slow-thinking, long-experienced and successful business man; the financier of mature years; the long-practiced successful physician; the long-practiced, serious-minded lawyer; the well-fitted and deliberate judge at the bench; the long-experienced teacher; the well-fitted, right-minded clergyman; the rare gifted statesman; the truly great scientist; the truly great artist; the truly great musician; and lastly, orthotonicity may be found, in contrast of its relation to the characters enumerated above, as an aftermath of prolonged spasticotonicity in that class of individuals we already classed as of spasticotonic type or temperament. In other words, the spasticotonic temperament may, from two different causes, transform into orthotonicity: (1), because of an altered mental outlook upon life with a consequent change of emotions (a normal attribute), and (2), as the result, due to some cause or other, of an almost totally depleted general nerve reserve, followed by a sort of indifference of the *will* power, with a consequent giving away of all muscular spastic tendencies (an abnormal attribute). Since such a changed condition is possible, *i. e.*, the transformation from one type to the other, and the changes, of necessity, must rather be slow and prolonged, it must become evident that while such changes take place the distinctive element which characterizes spasticotonicity and orthotonicity becomes rather somewhat obliterated, hence the observer must, by a sort of process of elimination, guardedly place the case under proper classification. To the practiced observer, however, it becomes an easy matter.

We shall here repeat that when we make use of the terms *spasticotonic* and *orthotonic* we do not mean to imply that the former denotes a sort of a morbid ocular condition, and that the latter is a normal or healthy ocular status. These terms refer only to individual temperaments. But

we do hold, as our practical experience shows, that: *Latent or spastic heterophoria is likely to be found in the case of an individual of the spasticotonic type or temperament, while manifest true heterophoria is, as a rule, evident in the individual of the orthotonic temperament.* Of course, we may find individuals who may belong to either class of temperamental type, but who are possessed of an ocular refractive and coördination status as normal as human eyes can show. Yet, such a find would only tend to prove the correctness of our thesis if our philosophy already expounded in this text is an incontrovertible fact, namely, that nature hardly ever builds two things, in a biological sense, alike and perfect. Thus, therefore, the finding of an ocular status as perfect as we choose to call such only tends to prove nature's exception to her general rule.

III

The ocular reflex symptomatology of the two different temperamental types is likewise at variance. In the spasticotonic type the symptoms are generally subjective and at times very complex; while in the orthotonic type the symptoms are mostly objective.

As a general rule the spasticotonic type of patient, who is subject to latent or spastic heterophoria, pours out on us a train of complaints which can only be compared to the vicissitudes in the sufferings of Job; yet, no outward objective signs can often be seen around and about the eyes of the spasticotonic type patient. The sufferings of such patients, which take on the form of cephalalgias with great inability to prolonged near use of the eyes are real, and they deserve our greatest sympathy and our best efforts in ministering relief.

In contradistinction to the above, the orthotonic patient, subjectively, complains little of remote systemic feelings but at once directs our attention to the objective signs around the ocular region.

In this type of patient we generally find, objectively, all that goes with the classically known morbid structural changes which take place as the result of severe eyestrain; such as injected vessels of the bulbar and eyelid conjunctiva; chronic blepharitis with thickened and incrusted lid margins; hypersensitivity to light with a tendency to lachrymation; prematurely acquired corneal arcus senilis; great intolerance to swiftly near approaching objects in front of eyes; inability to gaze at the eyes of the second person addressed in speech. Other structurally more destructive objective eyestrain signs are the chalazia with the sometime graver, destructive and irreparable disease known as dacryocystitis, and so on.

We can advance no other reason for the spasticotonic heterophoric's *subjective* complaints, and for the orthotonic heterophoric's *objective* ocular structural morbid changes than that the former, as we have already pointed out, belongs to a class of individuals whose nervous influence is always below par, hence such a subject's physical functions are more or less associated with pain and consequent mental unrest. Therefore, such a subject is more apt, on account of his ocular disturbance, to take matters in time and seek relief before any kind of structural changes take place. On the other hand, the latter belongs to a class, as we have also pointed out, who is full of reserve nervous energy and such a subject, notwithstanding any ocular coördination maladjustments, so long as this coördination is not associated with pain—as is the general rule in the emotionally passive and robust individuals—is more apt to neglect attention to the anomalous ocular condition until the organic ocular structures break away as the result of overstretching or pulling which becomes necessary in order to satisfy the psychic binocular fusion sense.

It is our aim, in another paper, to treat this subject from the standpoint of the differential diagnosis between orthophoria and heterophoria, real or spurious, manifest or

spastic; and we shall then outline our *modus operandi* for the same together with our method in applying the treatment which eventually leads up to the prescription of the proper prism combination, to be used in the position of rest, for the amelioration of all true heterophoric tendencies effected by the *straight* extrinsic ocular muscles.

Pueblo, Colorado

Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

Samuel H. Robinson, O.D., F.O.S.

CHAPTER III

The Duction Tests

The Three Steps in Ocular Muscle Work

IN ocular muscle work it is necessary that the refractionist shall first understand the purpose and relation of the three grand steps involved, before he can properly administer to those in need of such service. These steps are as follows:

1. *Muscle or Phoria Tests*

From the muscle or phoria tests are discovered:
(a) If any muscular imbalance exists
(b) Which are the faulty muscles
(c) The degree or extent of the imbalance present. This portion of the work has, however, already been covered.

2. *The Duction Tests*

From the duction tests one discovers the actual strength or pulling power of the extrinsic muscles, thus uncovering the true status of the weak muscles.

3. *Oculo-Prism Treatment*

After having determined which are the weak muscles and their degree of impairment, exercising these muscles to the extent of developing normal duction power and establishing a proper muscle balance, is the final step and ultimate aim to be desired.

Thus far, we have discussed but the first step in ocular muscle work, the testing for imbalance of the extrinsic eye muscles. We are now ready for the second step—a determination of the duction power of these muscles.

Purpose of Duction Tests

When making *duction tests* it is sought deliberately to approach a state of diplopia by shifting, by means of prisms, images from the foveae to other portions of the retinae. The more prismatic power applied the farther are the images removed from the foveae, the farther must the eye muscles rotate the eyes to replace the images upon the foveae and overcome the diplopia and the more nervous energy must the eye muscles expend in accomplishing single binocular vision. Thus, by means of duction tests, is measured the maximum endurance or pulling power of the eye muscles and this is known as the *duction power* of the muscles. When the muscles cannot rotate the eyes sufficiently to replace the images upon the foveae, there has been used prismatic power beyond the duction power of the muscles and diplopia or double vision ensues.

Relation between Muscle Balance and Duction Power

While there is, of course, a general relation between the imbalances and duction powers of ocular muscles, there is, nevertheless, no mathematically exact comparison to be indicated. Of two cases of exophoria, for instance, one of which we will say is two degrees, and the other four degrees—both suggesting that the internal muscles lack innervation—it might be anticipated that the case having two degrees of exophoria should register a higher *adduction*, when in fact the adduction in both cases may be alike. Or, of two unequal cases of imbalance, it may even occur that the muscles showing the greater imbalance will show a respectively higher duction power. This should neither be surprising nor appear contradictory in view of the fact that the *muscle or phoria tests* express merely a *relation between antagonistic or opposing muscles*, while the *duction tests* indicate the *individual strengths of the several muscles.* To illustrate: A case of lateral imbalance registers 10 degrees *adduction* and 4 degrees *abduction;* numerically, the balance

may be represented by the ratio 10 to 4, or 5/2. Another case registers, let us say, 20 degrees *adduction* and 8 degrees *abduction;* its balance will be similarly expressed by the ratio of 20 to 8, which is also equal to 5/2. Thus we find two cases having identically the same muscle balance, yet in the one case the *adduction* is 10 degrees, while in the other, 20 degrees. We thus learn that the degree of imbalance suggests a relation between opposing muscles, but does not express numerically the duction power of any of the muscles.

Schedule or Standard for Duction Powers

In connection with the duction power of ocular muscles, there has been established a schedule or standard by which refractionists may guide themselves in studying and measuring muscular impulses. By means of this standard, the operator needs but ascertain the existing duction of deficient muscles and proceed to exercise them accordingly. This schedule is not an arbitrary one. It is the result of study and observation on the part of most competent investigators. According to such authority, the standard generally accepted is as follows:

1 The *normal adduction*, for both internals (combined), is *24 degrees.*

2 The *normal abduction*, for both externals (combined), is *8 degrees.*

3 The normal sursumduction for the upper muscle of one eye and the lower muscle of its companion eye (combined), is *4 to 6 degrees.*

Eye muscles that fall materially short of these duction powers are self-evidently subnormal and may be expected to contribute to that individual's conscious or unconscious disadvantage.

Facts to be Recognized when Making Duction Tests

It will be recalled how, in a former chapter, reference had been made to the relation between convergence and accommodation. It will be remembered how increased accommodation stimulates greater convergence. That is the reason why it is necessary that the patient wear his correction during muscle testing. It is very essential, for the same reason, that the correction be worn during the duction tests. But there is yet another condition to be considered. In spite of the correction, an eye does not necessarily undergo the proper accommodative relaxation afforded by lenses unless the eye is compelled to submit to the influence of those correcting lenses. In fixing the 20 foot letters at 20 feet, the accommodation is being truly placed in obeyance to the correction and, assuming the lens correction to be accurate, in no portion of the adduction as registered, may convergence, which is due to stimulation of the accommodation, be expected. To *insure complete accommodative relaxation, therefore, the letters on the chart, instead of the spot of light, are used when making duction tests.* A blur in the letters should immediately indicate a disturbance in the convergence, assuming the accommodation is relaxed, as it should be. This in turn should suggest that the prismatic power before the eyes is now sufficiently increased to be on the verge of breaking up single binocular vision. The slightest increase in power may now precipitate diplopia and, approximately at this time, a reading of the prisms should indicate the correct duction power. A spot of light does not offer the first evidence of blurred vision as readily as letters do, nor in fact does it induce that accommodative relaxation necessary to read small letters at 20 feet distance, which is so essential in order that duction may be registered free from any convergence.

To determine, therefore, correct lateral duction powers, there must be eliminated every influence that can creep in and contaminate, so to speak, the true duction readings.

In other words, unless the accommodation is fully relaxed, the so called adduction will be increased by the amount of convergence brought into play through accommodative effort. True adduction then, must contain no accommodative convergence as a part of it, and can be assured only when the proper correction is worn and when the letters on the chart, instead of the spot, are used for making the duction tests.

Principle Underlying the Duction Tests

In making the duction tests, the operator seeks to determine the maximum pull, in degrees, that any pair of muscles can exert in a given direction. In order that an eye shall rotate in a given direction, an incentive must be created for it. If, by means of prisms, single binocular vision has been broken up, we have created the necessary incentive for the eyes to rotate in order to replace upon the foveae images that have been removed from them and thus re-establish single binocular vision. Should a given amount of prismatic power fail to produce diplopia, we know the eye muscles have had the ability to rotate the eyes sufficiently to retain the images upon the foveae. Should the prismatic power be increased, and single binocular vision is still maintained, it is evident that the eye muscles are able to rotate the eyes still more and thus further prevent diplopia. When double vision has finally been created through increased prismatic power, the maximum duction power for those muscles has been reached and a reading of the prisms will express the measure of that duction.

Measuring Adduction

Supposing that we desired to make the test for *adduction* (to make the eyes turn *inwardly* as much as possible), we should place prisms, *apices in* (or bases out) before the eyes, and continue to increase them in power until two charts or sets of letters have become visible, indicating thereby that

diplopia had been effected. The maximum prismatic power, thus registered, just preceding diplopia is the correct measure of *adduction.* In normal cases, it should be possible to rotate before the eyes approximately 24 degrees of prism, *apex in* (base out), before diplopia takes place.

Measuring Abduction

Similarly, to measure *abduction*, prisms, *apices out* (bases in), are set before the eyes and gradually increased in power until two charts or sets of letters become visible. The maximum prismatic power thus registered, just preceding diplopia, is the correct measure of *abduction.* Normally, about 8 degrees will be reached before diplopia develops.

Measuring Sursumduction

To measure *sursumduction*, prisms are placed, *apex up*, (base down) before one eye and *apex down* (base up) before the companion eye; or, all the power may be placed *apex up* before one eye, or *apex down* before the fellow eye. The prisms are then very gradually increased, until two charts or sets of letters appear, one above the other. The maximum prismatic power thus registered, just preceding diplopia, is the correct measure of *sursumduction.* In normal cases about 4 to 6 degrees should be held before diplopia takes place.

Some General Principles as Applied to Duction Tests

For those who feel incapable of retaining more of the principles than just outlined, the above should suffice in assuring them of practical results in the work so far pursued. Many students, however, desire a more intimate knowledge of each step involved and for their benefit it will be well to review a portion of the work previously covered as applied, however, to the duction tests. To reiterate fundamental laws and principles is to establish them more firmly in the mind.

The Duction Tests—Futher Analyzed

As previously mentioned, we seek, when making duction tests, to determine the maximum pulling power of a pair of eye muscles in a given direction. Assuming that we are attempting to measure the *adduction*, it is necessary that the *internal muscles* be forced to exert their maximum pull by rotating the eyes *inwardly*. The incentive to the eyes to thus rotate is to avoid diplopia. They will do everything short of projecting themselves out of their sockets in order to maintain single binocular vision. They will, accordingly, rotate to the limit of their muscular endurance in order to replace upon the foveae images which

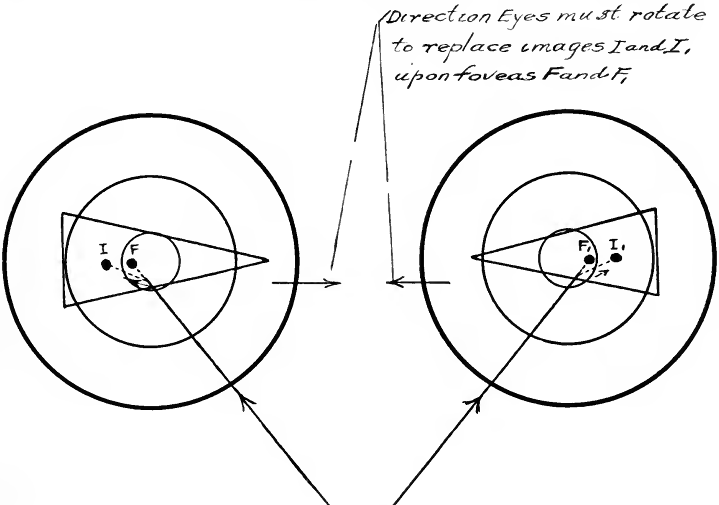


Fig. 44. Illustrating direction of eye rotations in order that the foveae may receive the images when prisms, base out, are placed before the eyes.

artificially (by means of prisms) have been removed from them. Referring again, to Fig. 18, we find that eyes rotate in a direction contrary to that in which an object viewed

appears to move. Or, to state it more accurately, *an object in space appears to move in a direction opposite to the rotation of the eye.*

When prisms, therefore, are set *apices in* (bases out) before the eyes (*vide* Fig. 44), rays from a point in space—which ordinarily (without prism interference) would focus upon both retinae at the foveae F_1 and F—will be deflected by the prisms so that the images are displaced upon the retinae in the direction of the *bases* of the prisms, or temple-ward, and assume the positions I and I_1. The eyes thus have an incentive to rotate *inwardly*, or *in a contrary direction*, in order to replace the images I and I_1 upon the foveae F and F_1 and continue to maintain or re-establish single binocular vision.

How the Measure of Adduction is Determined

When measuring the *adduction*, prisms are set *apices in* (bases out) before the eyes and gradually increased until the images on the retinae are so far displaced that the eyes are unable to rotate them back upon the foveae. This is to say, the more prism applied, *apices in* (bases out), the greater distance is I and I_1 removed from F and F_1 and the farther must the eyes turn *inwardly* (towards the apices) in order to replace the images upon the foveae. When so much prism has been applied and the images I and I_1 have been so far removed that the internal muscles are no longer able to rotate the eyes sufficiently to replace these images upon the foveae F and F_1, then the limit of the adduction has been reached and diplopia ensues.

The maximum distance that images may be removed from the foveae, with the internal muscles still capable of rotating the eyes inwardly so that the images will be replaced upon the foveae, expresses the adductive power of the internal muscles, and the prisms so shifting the images indicate in degrees the exact measure of adduction.

How the Measure of Abduction is Determined

Figure 45 illustrates in a similar manner that which occurs when measuring the *abduction*. In this case, however, the prisms must be set *apices out* (base in); the images are displaced towards the bases (nasal side of the retinae) and the eyes rotate *outwardly* (toward the apices), in order to replace the images I and I_1 upon the foveae.

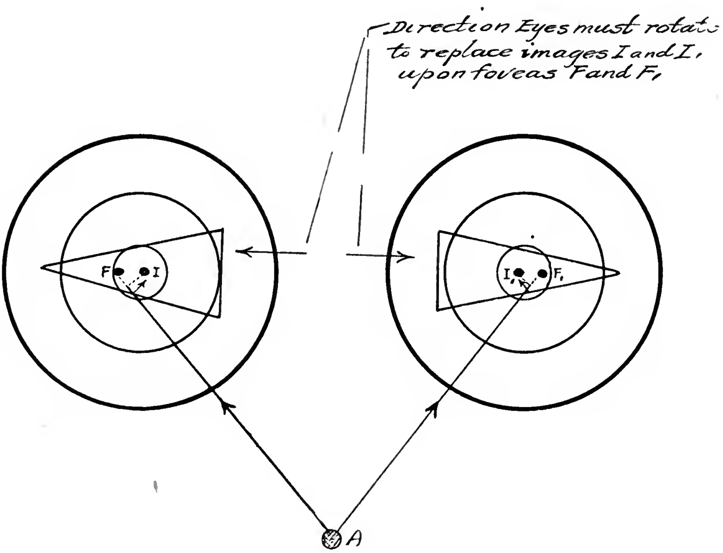


Fig. 45. Illustrating direction of eye rotations in order that the foveae may receive the images when prisms, base in, are placed before the eyes.

The maximum distance that images may be removed from the foveae, with the external muscles still capable of rotating the eyes outwardly so that the images will be replaced upon the foveae, expresses the abductive power of the external muscles, and the prisms so shifting the images indicate in degrees the exact measure of abduction.

Figure 46 illustrates the same principle expressed in Figs. 44 and 45. It covers, however, the measure for *sursumduction*.

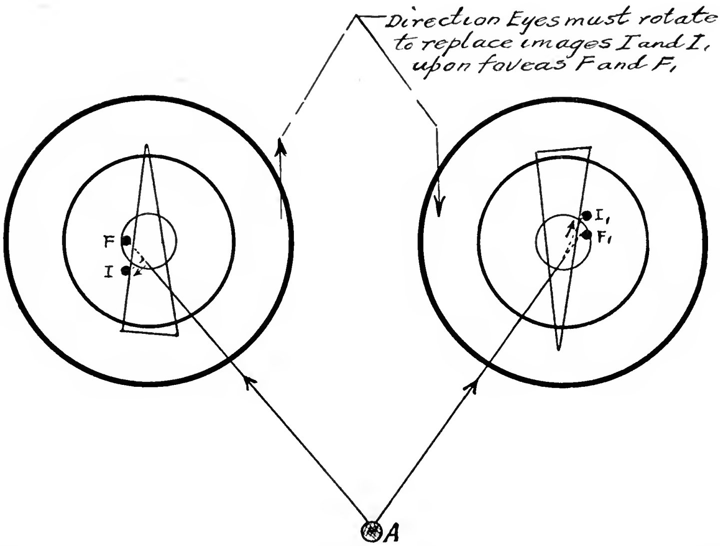


Fig. 46. Illustrating direction of eye rotations in order that the foveae may receive the images when prisms, base up before one eye and base down before the other eye or *vice versa,* are placed before the eyes.

Effect of Total Prismatic Power before One Eye

Should a single prism—the combined power of the two prisms before both eyes—be placed before one eye, the displacement F I or F_1 I_1 will necessarily correspond to the total value of the prism before that eye. That is to say, if the prismatic power had formerly been divided equally between the two eyes, and the total amount is now placed before a single eye, the distance the image is displaced upon that retina will be twice as great as formerly when but half the prismatic power was held before that eye. The eye, therefore, will not rotate twice the distance in order to

replace the image upon the fovea and thus re-establish single binocular vision.

In spite of the seemingly logical conclusion that an eye subjected to prismatic influence and a consequent rotation would alone undergo all the stimulation effected by the prism before it, while its companion-eye, without any prism before it and without the duress incident to rotation, could in nowise share in the prismatic influence afforded by the prism before the fellow eye, it is the opinion of competent investigators that *prismatic influence is divided equally between both eyes, regardless of how the prisms are divided with respect to each eye.*

The author is unable to state if such equal participation in prismatic stimulation is apportioned in equal measure to the corresponding muscles of both eyes, or expresses merely an equality in total innervation for each eye without regard for uniformity in the stimulation experienced by the corresponding muscles individually. If it means the latter, the matter of choice between using a single prism before one eye or equal amounts of prism before both eyes during muscle exercise would seem to be quite significant.

While in making duction tests there seems to be no difference in the total duction registered when the same is measured with a single prism before one eye, or with the same amount of prism power equally divided between both eyes, one cannot easily disprove the suggestion that total prismatic power before a single eye is perhaps not apportioning in equal measure stimulation to those muscles which it is especially desired to exercise. For that reason, the writer would feel very reluctant to institute muscular treatment to attain normal adduction, for instance, by conducting his exercises with increasing prisms, *apex in*, before a single eye, throughout the treatment. For, having attained the desired duction reading, he could scarcely be justified in believing that both internal recti have equally participated in the exercise and have been equally stimu-

lated. The fact that one can achieve as high a duction reading with a single prism before one eye, as with the same amount of prism equally divided between both eyes, is no conclusive evidence *per se* that the corresponding muscles in the two eyes have been equally exercised. Thus, what may be correct procedure in performing the *duction tests* is perhaps not the ideal practice when administering *muscle exercise*.

Without essaying to give clinical proof in behalf of the attitude here expressed, suffice it to say that the author in all his *muscular exercise* pursues the plan of rotating prisms before both eyes simultaneously, and in quantities as near equal as training and skill make possible. In any event there can then be little question that uniform and harmonious stimulation is enforced and a coördination maintained essentially helpful to all binocular considerations.

How to Measure Adduction and Abduction with Rotary Prisms

To dispense with confusion or uncertainty in the manner of executing *lateral duction tests*, the student is referred to Fig. 47. Rotary prisms are placed before both eyes, with

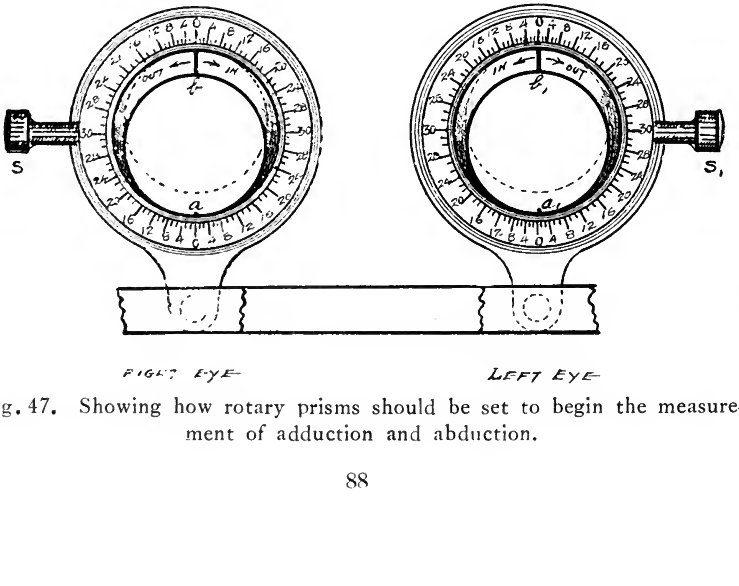


Fig. 47. Showing how rotary prisms should be set to begin the measurement of adduction and abduction.

thumb screws S and S_1 *at the sides* (horizontal), and the base indicators, b and b_1 at *zero* (vertical). Points a and a_1 are the *apices* of the prisms. It will be observed that as the *bases* b and b_1 are rotated *outwardly*, the *apices* a and a_1 must turn *inwardly;* and as the bases turn *inwardly*, the apices must rotate *outwardly*. This relation should be firmly established. It has been the purpose throughout this treatise to deal with prisms in terms of their apices. As previously explained, the apex is the direction of ocular rotation effected by the prism. It denotes the direction in which the eyes always rotate, and for that reason simplifies the use of the prism, inasmuch as *direction* or *rotation* is the thing uppermost in the mind when applied to the eye. Rotary prisms, however, are designed with their *bases* instead of *apices* indicated. The operator must follow the *base* of his prism instead of the *apex* when performing his tests. When the relation between *base* and *apex* in the matter of eye rotation is firmly established in the mind, the operator will have no difficulty in handling his prisms. To affect rotation of the eye in a given direction, rotate the *apex* in the *given direction*, or, rotate the *base* in the *opposite direction. As one follows the direction in which the base moves, one knows the eye is rotating in contrary direction; and in order to cause the eye's rotation in one direction, the base must be turned in the opposite direction.*

Thus in measuring *adduction* with rotary prisms, we begin as illustrated in Fig. 47 or above indicated. The thumb screws S and S_1 are turned *slowly*, so that the *bases* b and b_1 are rotating outwardly (the *apices* and eyes are thus turning *inwardly*). When the patient states that two charts or sets of letters are visible, turning of thumb screws must cease immediately and both scales on the prisms read; the combined reading is a measure of the *adduction*. Since double vision has been thus established, one knows that the prismatic power now before the eyes is in excess of the endurance or adductive power of the internal muscles. Reasonable

practice will teach the operator to rotate both prisms with proper uniformity and in the desired direction. When the total reading falls materially short of 24 degrees, a low state of innervation in the internal muscles is clearly indicated, and prism exercise should prove beneficial if not absolutely essential.

In like manner to measure the *abduction*, rotary prisms are again set before the eyes as in Fig. 47. In this case the eyes are to be rotated outwardly; hence the apices must be turned in that direction, or the *bases inwardly*. The prisms are thus rotated slowly until the patient experiences diplopia, when rotation must quickly cease and both scales be noted. The combined reading in degrees is the measure of *abduction*. When the total reading is materially less than 8 degrees, a weakened state of innervation in the external muscles is made evident and muscle exercise becomes advisable.

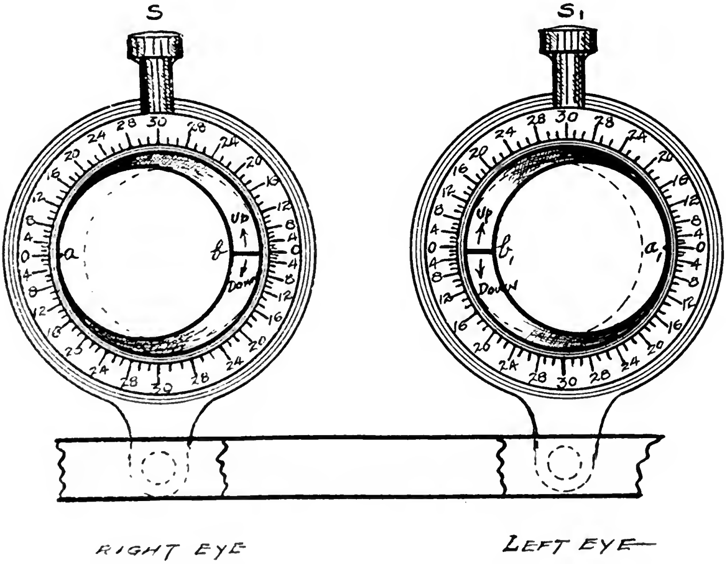


Fig. 48. Showing how rotary prisms should be set to begin the measurement of sursumduction.

How to Measure Sursumduction with Rotary Prisms

To measure sursumduction (vertical duction), set rotary prisms as indicated in Fig. 48—thumb screws S and S_1 *at the top* (*vertically*), and base indicators b and b_1 at *zero* and *horizontal*. As the patient fixes the letters on the distant chart, the prisms are rotated *slowly* (in either direction, apex up or down, when using but one prism, and in opposite directions, one apex up and the other down, when operating both prisms), until two charts or sets of letters become visible, when rotation quickly ceases and the scale is read. This will be the measure of the *sursumduction*.

Care to be Exercised when Using Rotary Prisms

It will be noticed that the first few graduations are very close together on the rotary prisms. It should not be surprising, therefore, to find that, upon what appears to be the slightest rotation, sufficient prismatic power is placed in position to create diplopia. This is especially true in the vertical tests as the duction power of those muscles is normally low.

This error in technique creeps into the work of the beginner who has not yet developed the poise so essential in all ocular muscle work. In the vertical tests, when both prisms are used, the minutest care must be exercised. With a normal duction of but 4 to 6 degrees, each prism has a range of but 2 to 3 degrees. Only one fairly skilled will so rotate his prisms as not to exceed the duction of the vertical muscles at the first turn generally. Thus diplopia is often created before one has even begun the work. This and other difficulties are thoroughly discussed in the following chapters, under the subtitle "*Difficulties Encountered.*"

CHAPTER IV

Oculo-Prism Treatment—General

Introductory Remarks

THE subject of ocular muscle exercise or treatment has for some time been engaging the thought and attention of the studious refractionist. To have studied and elaborated for years upon the action of a small intrinsic eye muscle which controls the focusing adjustment of the eye and to have practically ignored the coöperative extrinsic muscles whose functions are simultaneous and correlated with that of the ciliary is quite beyond the comprehension of the modern investigator.

To be sure, extrinsic ocular functions have been closely studied and the information gleaned, systematized and recorded. One is taught, for instance, that there exists a relationship between convergence and accommodation. This subject has been much elaborated upon. There has also been established an accepted standard of duction power for each of the several pairs of extrinsic eye muscles. Imbalances are now determined, measured and recorded. In the higher field of ocular muscle investigations, subtle impulses and strange forces are minutely traced to lobes in the brain, there to remain in undisturbed oblivion. But to what purpose is all this?

There are those who yet oppose muscle exercise. What can be their purpose? Shall we ignore a low state of innervation because there is yet no diplopia or muscular asthenopia? Then we may argue that one or more diopters of refractive error shall go uncorrected because the patient is indifferent to a blur or unconscious of stress or pain in the ciliary body. Or, is it considered better to prescribe prisms? Then it must be better to prolong and aggravate a defect than to eliminate it in whole or part through exercise. Or, again, can it be the judgment that prisms be prescribed in highly weakened states of innervation and

lesser defects be ignored? Then it would be equally reasonable to correct high refractive errors and ignore the lesser ones. Shall it be said that refractive correction alone can strike effectively at the root of all innervational disturbance; then the study, experience and close observation of careful students in the field of ocular muscles must be placed at naught and the *lens* enshrined as the sole and universal panacea for all ocular anomalies. There can, in fact, be just one answer to these questions. *Give muscle treatment in every instance where subnormal duction exists, after the proper refractive correction has been administered; prescribe prisms when exercise fails and prism support alone can satisfy the condition.*

It is well recognized that a substantial degree of refractive error will cause a blur in vision if uncorrected, and when self-corrected may develop strain through the focusing apparatus. In the one case, an improper optical adjustment produces a blurred or indistinct image; in the other, the effort at self-adjustment develops stress and pain through the ciliary body. Yet its replica in the extra-ocular functions is passed practically unnoticed. It has been taught that unless both eyes properly fix an object, diplopia or blurred vision ensues; but somehow, the correlated fact has not been emphasized that, if the extrinsic muscles undergo special effort in maintaining single binocular vision, strain in these muscles may be expected to follow as inevitably as that experienced by the ciliary body. Just as an hyperopic eye suffers its greatest strain when used for near work, equally so does the exophoric eye suffer the severest when at near work. Just as a myopic eye sees least distinctly at a distance, to that degree does the esophoric eye suffer the greatest when looking at a distance. And just as the myopic eye without correction sees clearly at close range, to the same extent does the esophoric eye, though uncorrected, experience a sense of ease when converging for the near point. Surely, there is some significance in all this.

There are those who contend that if *exercising* the extrinsic muscles is preferable to *prescribing prisms* for their defects, why not similarly exercise the ciliary that it may correct its own defects without strain, instead of correcting the defects with lenses? On the face of it, the argument appears sound and plausible. Yet certain facts are overlooked. When the ciliary corrects a refractive error due to an ocular deformity, there is expended through it nervous energy beyond that normally required for accomplishing accommodation in the emmetropic eye. With every act of vision, that eye suffers not through its inability to perform *regular* and *normal* functions, but because of extra and undue accommodation imposed on it. Who knows but that a form of ciliary exercise may yet prove of some service (especially in early presbyopia)?

This we know on the face of it: to inaugurate a system of ciliary exercise is to engage on the side of the *abnormal.* It is training and developing the ciliary to perform work beyond that apparently intended by nature. On the other hand, the institution of ocular prism exercise is confined entirely within the field of the *normal.* Here one deals *not* with *anatomical deformities* but with *suppressed* or *insufficient nervous impulses.* Here one does not attempt to raise the ductive powers of muscles beyond determined or prescribed standards, but rather to develop innervations so as to meet a normal and essential standard. The purpose and effect of the two types of exercise is obviously dissimilar. In the one case, exercise as advocated will produce an *abnormal* muscle; in the other case, the aim is merely to approach a state of *normalcy.*

Too few who disparage muscle treatment speak from ripe experience. It is probably safe to state that such persons have never seriously engaged in ocular muscle work. It is more than probable that after several perfunctory and fruitless attempts they have abandoned it as a visionary practice without real merit or opportunity. Too much

criticism has thus been foisted upon a *work* when the same should have been directed instead at the *worker*. The author has personally experienced all the trials and vicissitudes incident to beginning the practice of ocular muscle work which those now less sanguine and enthusiastic have experienced. In the beginning he too was prone to court the pessimism and entertain the disfavor which many others flaunt at present. Many of the happiest thoughts and successes, however, are often achieved through single incidents, such as the following experience should illustrate.

A prominent citizen from an adjoining city had called upon the author some years back with a case of refraction. Eager to please, every effort had been exercised to do the work agreeably and satisfactorily. The patient, an austere looking man of about fifty, accepted his glasses, which were prescribed for reading, with apparent approbation. At that time, the writer knew only the principles of muscle work, and, as many of today, considered them too vague and impractical to incorporate into daily practice. In less than a week the patient returned, stating that the glasses were unsatisfactory. For several moments vision, he declared, was cleared and comfortable, after which a blur and increasing pain about the eyes followed. The author, recalling the care he had exercised in making the correction, felt quite at a loss as to how to proceed in locating the difficulty. Another test was made, however, and the same refractive error uncovered. The thought of a muscle imbalance now suggested itself. A muscle test disclosed considerable exophoria. Believing that a weakened state of the internal muscles was thus indicated, the reason for difficulty in reading became apparent. However, how to then proceed was the "great problem." The author remembered vaguely something about normal duction powers. He should know what this man's adduction measured, as suggestive of how badly deficient the internal muscles might be. With difficulty and apprehension the measure of

adduction was finally accomplished and it measured 8 degrees. It was self-evident that the difficulty was in the internal muscles—but what to do next was a mental void.

The idea which then occurred was that, by reducing the correction and receding the near point, less convergence would become necessary and correspondingly less strain could be anticipated through the internal muscles. The patient was accordingly asked to return for his glasses at a specified time and upon delivery was assured that these would prove satisfactory. In leaving, however, he volunteered the assurance that he would again return should these prove unsatisfactory. True to his promise, he returned in about ten days and, presenting his glasses, inquired with some emphasis if it were not possible for him to be properly fitted. The writer, having anticipated more trouble, had read in the meantime everything he had available on ocular muscles, visualizing as to how to give muscle exercise. He had practiced on himself, on his assistant and on such meekly disposed friends as had the misfortune to come within the precincts of his optical sanctum. In spite of all this, he had not the courage when his patient confronted him to recommend muscle treatment. Instead, he decided to incorporate prismatic correction, *apices out*, and with more profuse assurance dismissed his patient.

In due time, the glasses for the third time were delivered and complete satisfaction hopefully prophesied. Such good fortune was not yet in store, nor was this individual seeking satisfactory glasses to be discouraged. In about four weeks this patient returned, stating that until recently the glasses had been perfectly satisfactory, but that they were again beginning to annoy him and wanted to know what could be done for him?

This time, the writer cast hesitancy and fear to the winds. Inviting his patient to a chair in a more sequestered recess of his refracting room, he began to outline slowly and methodically the conditions involved in the case. The

plausibility of the facts as presented made a deep impression and a course of treatment was accordingly agreed upon. There remained but one cause for apprehension. At the age of 50 years it seemed that but slight response could be elicited from the extrinsic muscles. Nevertheless, the work was entered upon with unprecedented zeal and enthusiasm.

Adduction, which had formerly (before having prescribed prisms), measured 8 degrees, now registered but 4 degrees. After the first day's exercise, adduction with some difficulty was raised back to 8 degrees. At the following treatment, two days later, adduction opened with 6 degrees and reached 10 degrees at the conclusion of that treatment. After six treatments, adduction was developed to 24 degrees. Allowing for a natural ebbing which duction undergoes after each exercise, the experienced operator always seeks to build up the duction beyond standard if possible. This expediency the writer soon learned for himself from the fact that at the beginning of each treatment an appreciable decrease in duction was noted as compared with that at the conclusion of the preceding treatment. This is due to what may be termed an "innervational overflow" due to special concentration on the part of the patient during exercise. This surplus stimulation subsides, however, after a period of rest and the duction will be found lower but more or less permanent.

For this reason, the writer continued to develop the adduction until the patient, in spite of his age, could overcome 48 degrees of prism, *apices in.* With this adduction remaining in force for several days, treatment was then concluded. The above results were attained within nine treatments. The period of exercise varied from twenty minutes to one hour. Other operators, it has since been observed, recommend shorter periods of exercise. It seems, however, that the duration of exercise must be worked out for each individual case.

One objection to protracted periods of exercise is that the average practitioner feels he can ill afford to devote much time to each treatment. In the work which follows, however, a method is outlined which provides treatment for several patients simultaneously. This will eliminate the time factor and insures at a single sitting exercise sufficient to break up, in certain cases, a "muscle resistance" which can be overcome only through reasonably prolonged exercise. It is also important that, in starting a course of treatment, the same shall be administered each day, or each alternate day consecutively. In this way the influence of one treatment may be expected to overlap that of the succeeding one. This steady stimulation is essential in order that induced innervations shall become permanent and the effect of each treatment shall not have dissipated before the succeeding treatment can stabilize it.

In the case above illustrated, it may prove interesting to add that the patient was finally given the lenses originally prescribed for reading; that these have been used continuously for a period of two years with utmost comfort; that a later slight annoyance disclosed a lowered adduction which was remedied after two treatments and comfort again restored. Since then, the author has been enthusiastically engaged in this work and the numerous cases that have passed successfully under his hand attest unquestionably to the merit and stability of this branch of ocular work.

Practitioners from time to time are questioning the practicability or infallibility of ocular muscle work. In reply it must be stated that there is no accepted work in which the results are so uniformly invariable as to preclude a single exception or variation. The practicability of any method must not be judged by its periodic failures but by its more frequent and wider range of successes. That which alone can solve a difficult problem or, which alone, can surmount an unusual difficulty, is worthy of use and

may duly take its place in the ranks of the indispensable.

No type of work is absolutely infallible, nor can one method uniformly satisfy every condition or situation. In observing ocular muscle anomalies, it is found that various conditions demand various forms of treatment. Oculo-prism treatment does not project itself as a perfect and general panacea for all forms of ocular muscle disorders. A total paralysis of an extrinsic ocular muscle certainly cannot be expected to respond to muscle exercise. Similarly, a partial paralysis, or muscular palsy, may anticipate no response, though an attempt at treatment may sometimes be deemed worthy in behalf of study or investigation. The fault of anatomically malformed muscles, *e. g.* muscles that are too long or too short, cannot fundamentally be attributed to deficient innervation; hence, one need neither seek nor hope to find relief through exercise in such anomalies.

The exceptional cases of *erratic impulses*, which at one time possibly show a state of esophoria while at another—under the influence of subtle and inexplicable forces— perhaps indicate exophoria or some condition of tropia need, likewise, *not* be classed as ideal cases for ocular muscle treatment. Just as refraction deals with *ocular functional disturbances* in *healthy* eyes that are malformed, and *not* with *pathological* conditions, so does oculo-prism treatment deal with *subnormal* but *comprehensible* innervations and not with those disturbances which are the product, perchance, of a *deranged nervous system*, intractable and ungovernable.

For every *valid* case which the serious practitioner may be able to indicate as incorrigible or unresponsive to ocular muscle treatment the author can possibly present five to ten similar cases which have responded more or less readily to such treatment. That prism correction has its province in refractive work is not to be controverted, but that many cases would have fared better under *prismatic exercise* than *prismatic correction* is similarly true, as has been evidenced in practice as well as theory.

To some, ocular muscle treatment as here outlined may seem conspicuously presented as the only available means for relieving extra-ocular disorders. Inasmuch as the present text is wholly designed to expound muscle exercise in its own peculiar adaptation to extrinsic ocular muscles insufficiencies and its consequent asthenopia, it should not be interpreted as a defiance to other remedial methods which may, and often should, be associated in the interest of desired alleviation. The fact is that oculo-prism treatment in many cases can supply but a portion of the desired results unless coördinated with such help as will be further outlined.

This is directly in line with arguments presented by a few earnest but misguided refractionists who contend that muscle exercise is impractical and inefficacious inasmuch as, fundamentally, innervational insufficiencies represent deficient circulation, nutrition or absorption. In other words, they represent functional disorder which should be treated at its source — systemically, perhaps, or in some other manner which might correct the seat of disturbance.

Undoubtedly, neurosis is largely responsible for functional derangement as is anemia also, in which deficient impulses may be directly attributed to a condition of the blood and subsequently poor nutrition or *vice-versa.* But why should these argue against muscle exercise? Shall the anemic be denied the benefit of fresh air, suitable walks and outdoor exercise, because his system requires rehabilitation from within as well as from without? What seems truly essential is that both or all forms of correction be utilized for the sake of special contribution of relief and comfort.

Maddox in his work, *The Ocular Muscles*, page 230, states as follows: "Javal and others have shown how very much the horizontal relation between convergence and accommodation can be altered by systematic training, and when marked heterophoria is not relieved by the correction of refraction, I have come to believe, it is far better to use training prisms than relieving ones."

A deficient innervation in the extrinsic ocular muscles due to a state of general nervous debility, or to a condition of anemia, should not be expected to respond readily and at times even perceptibly to ocular prism treatment. It is apparent, of course, that any local stimulation afforded by ocular muscle exercise is so slight in comparison to the stimulation required by the entire body that its effect or influence becomes quickly dissipated, but what is more obvious is the fact that the body itself, which represents the reservoir of nervous energy, is already so thoroughly depleted that it fails to supply even the limited energy necessary to support a successful course of muscular exercise.

This explains readily why persons who are extremely weak and anemic make unresponsive and unsuccessful subjects for oculo-prism treatment. The entire body, for example, when afforded the stimulation of fresh air and outdoor exercise cannot thrive on these alone, but must partake as well of wholesome and nutritious food in order that the effort made in pursuit of better health may not be fruitless or wasted.

It should be apparent, therefore, how essential it is that when exercising ocular muscles, a sufficient nervous reserve force be provided the body in order that adequate "ammunition" shall be at hand with which to prosecute the work. It becomes, therefore, imperative that the refractionist, when pursuing ocular muscle work, shall in every case be solicitous of the general good health of his patient, both in the interest of the latter's physical welfare, and the success of his own labor and treatment. Thus, upon a cursory survey, when the refractionist observes evidence of a depleted nervous system—a thin, gaunt and emaciated body on the part of his patient—he may begin his treatment, if he so chooses, but to anticipate any marked success he must quickly apprise his patient of the fact that systematic rest, wholesome food, and above all perhaps, the immediate

care of a good physician is a most essential corollary to the work in hand. The advice in many cases may prove the more valuable portion of the treatment, but the refractionist nevertheless has rendered a service which, be it advisory, active or both, is typically professional work and will earn the respect and gratitude intrinsically due him. Practitioners will marvel at the scores of devoted friends and patients that are thus made. There is earned a respect and confidence absolutely not to be so attained in other branches of refractive work.

Prescott, Arizona

[To be continued]

Abstracts and Reviews

The Photochemistry of the Sensitivity of Animals to Light

Selig Hecht, Ph. D.

THE stimulation of certain animals by light furnishes the opportunity for an objective and quantitative analysis of the underlying mechanism of photoreception. The reason for this is that both the stimulus—the light—and the response of the animals—a qualitatively invariable retraction reflex—are capable of precise and easy control. Fortunately the characteristics of this sensitivity are not peculiar to these particular animals (a clam and an ascidian), but are to be found in one form or another generally distributed among animals possessing a light sense. The present analysis is therefore of broad application in its fundamental ideas.

The characteristics referred to are as follows. (1) A measurable interval, the reaction time, intervenes between the beginning of the application of the light and the beginning of the response. (2) A response is elicited only when the intensity of illumination has been increased. (3) Once a response has been given to light, the continued application of the same intensity fails to produce any additional effect. (4) If, following this, the animal is placed in the dark, it soon recovers its sensitivity to the intensity which had become ineffective. The investigation of each of these characteristics has resulted in the formulation of certain principles and in the postulation of an hypothesis for their explanation.

A study of the reaction time shows first that it represents practically the time taken up in the sensory process alone, the conduction of the impulse and the early part of the

response taking almost no measurable time in comparison. Second, it shows that the reaction time represents two definite intervals. The first is the sensitization period, or the time during which illumination is actually necessary. The second is the latent period, or the time during which the animals may be in the dark, and at the end of which the animal gives its response as if it had been illuminated all the time. In the clam, *Mya arenaria*, the sensitization period may be 1/100 second or even less, depending on the intensity. The latent period, however, is constant, and lasts about 1.5 seconds. The discovery of the complexity of the reaction time opened up the field for quantitative investigation.

The action of light in the photosensory process is probably photochemical. Experiments show that this action possesses the ordinarily well-demonstrated properties of photochemical reactions. First, the relation between the intensity of illumination and the sensitization period, or time of necessary exposure, follows the Reciprocity Law of Bunsen and Roscoe. The product of the two variables is equal to a constant. Second, the temperature coefficient of the action of light on the sensory activity of these animals is very low, near 1 for a rise of 10°C. This is in contrast to the temperature coefficient of ordinary chemical reactions which is usually between 2 and 3. Therefore, no matter what the temperature, a definite quantity of photochemical transformation is required to produce a stimulating effect.

The light adaptation of these organisms is well marked. They fail to give more than a single response even to intense sunlight. Dark adaptation is equally prominent. Studies of the rate and course of dark adaptation furnish the clue to the photosensory mechanism. In the dark the quantity of light required to elicit a response is at first very large. Gradually the amount of light necessary for a response decreases, at first rapidly, then more slowly, until after a definite interval it becomes a constant minimum. This

means that less and less photochemical decomposition is required during dark adaptation to produce the same response.

During light adaptation the light decomposes a sensitive substance, and at the same time causes a decrease in sensitivity. During dark adaptation it is possible that the return of sensitivity is the result of the formation of fresh sensitive material. If we assume that the action of light is to break up a sensitive substance into its precursors, and that in the dark these precursors reunite to form the sensitive material, all the data acquired in these experiments may be explained in terms of the kinetics and dynamics of chemical and photochemical reactions whose general properties are well known and mathematically predictable.

The course of dark adaptation is found to follow with great accuracy the kinetics of a bimolecular chemical reaction. There are therefore *two* precursors (P and A — precursor and accessory) uniting to form the sensitive material (S). The reversible photochemical reaction is then

$$S \underset{\text{“dark”}}{\overset{\text{light}}{\rightleftarrows}} P + A$$

and all the results fit this stoichiometric equation remarkably well. Moreover, certain predictions which can be made from it, have been tested, and have been verified on a number of occasions. For example, the "dark" reaction, P + A → S, is an ordinary chemical reaction. Its temperature coefficient should therefore be between 2 and 3 for 10°C. This reaction represents the process of dark adaptation, and experiments show that dark adaptation in these animals has a temperature coefficient of 2.4.

The phenomena so far considered are those concerned with the sensitization or exposure period. But these animals possess a very definite latent period which very frequently is of longer duration than the sensitization period. A study

of the latent period shows that it represents the duration of a process closely connected with the products formed by the primary photochemical reaction. The velocity of this process turns out to be a linear function of the concentration of precursors, P and A, formed by the light.

From this and other evidence the following explanation of the latent period has been proposed. During the latent period an inert material, L, is changed into a chemically active substance, T, which then acts on the nerve to produce the outgoing sensory stimulus. This reaction, L → T, is catalyzed by the presence of the freshly formed photochemical decomposition products P and A.

Thus the latent period reaction becomes really the principal reaction in the sensory process. It is all set and ready to go, and requires only that the light change S into P and A so that the latter can catalyze the transformation of L into T. The whole photosensory mechanism may then be summed up in the two reactions

$$S \rightarrow P + A; \quad L \parallel P + A \parallel \rightarrow T$$

in which $\parallel$ P + A $\parallel$ means catalysis by one or both of the precursors. The first reaction occurs during the sensitization period; the second during the latent period.

This rather concrete hypothesis has proved to be a useful tool in getting further knowledge, because of experiments designed to test it in various ways. A few of these tests may be briefly mentioned. The latent period is supposed to be a simple reaction, perhaps an oxidation. Its behavior with the temperature should therefore follow the equation deduced by Arrhenius for the relation between the velocity constant and the absolute temperature. Experiments show that the reaction L → T does follow this prediction accurately. Moreover, the value of the constant $\mu = 19{,}680$, found for the reaction is in accord with those usually found for hydrolyses, oxidations, etc., in pure chemistry.

Another test concerns the interrelations between the exposure and the latent period. If the intensity of the stimulating light is constant, the velocity of the latent period reaction is found to be directly proportional to the time of exposure. On the other hand, if the time of exposure is kept constant, and the intensity varied, the velocity of the latent period reaction is found to be proportional to the logarithm of the intensity. If now both time and intensity are varied, the velocity should be proportional to the product of the time and the logarithm of the intensity. Experiments prove this to be true.

A perhaps more significant application of the hypothesis has been made to the dark adaptation of the human eye. A proper analysis of the dark adaptation data has shown that the process in the human eye is fundamentally similar in principle to the process occurring in the clam and the ascidian. As a result there has been opened up a new field of investigation in retinal photochemistry which may some day enable us to possess a reasonable theory of vision.

(Abstracted from the *Journal of the Optical Society of America*, Vol. V, p. 227, 1921.)

Hints in Relation to the Dynamics of the Extrinsic Ocular Muscles

J. M. Banister, M.D., F.A.C.S.

THE author opens his paper with the query:—"Are we not prone to examine the refraction in states of asthenopia, and to content ourselves with the correction of any ametropia detected, without looking very deeply into the manner of the performance of the highly coördinated muscular functions necessary to efficient and easy use of the eyes?"

The amount of abduction, adduction, sursumduction and deorsumduction to be found in the absolutely normal ocular

apparatus of the healthy individual should be taken into account in clinical work, and also the requirements of the physiologic coördination of these muscular functions to secure the normal and healthy use of the eyes.

The results of the writer's clinical investigations justify the following:

1 That the degree of adduction (prism convergence) given by most writers as proper for 6 metres, varying from 30° or 35° to 45° or 50°, cannot be reached by healthy eyes except after practice in the use of prisms. Hence the standard is too high for attainment in the first office examination, and hence the method of measuring the convergence by adductive prisms is unreliable and misleading.

2 That the prism convergence for near (33 cm.) is also misleading and is not an accurate test of the real power of convergence.

3 That the determination of the punctum proximum of convergence, with the calculation of the maximum of convergence in meter angles after the method of Landolt, is the only true test of the real power of convergence, or the *positive convergence*.

4 That contrary to the generally received views, abduction (prism divergence), can fall well below 6° in healthy eyes, and that consequently, it is wrong to assume, upon this basis alone, that such cases are pathologic.

5 That there exists in healthy eyes no positive, definite relation between prism convergence and prism divergence for distance, and that it is not correct to claim that such eyes should, without practice with prisms, show at 6 metres a ratio between these functions of 3 to 1 (Risley), or 7 to 1 (Noyes), in favor of convergence, not permitting abduction to fall below 6°.

6 That we may expect sursumduction and deorsumduction for distance to be about the same in degree. In about 70 per cent of healthy eyes each function reaches 2° (prism) in amount.

7 That in healthy eyes orthophoria exists in about 60 per cent of the cases for distance, and in about 82 per cent for near, and that it is wrong to hold that orthophoria for near is abnormal and to be viewed with suspicion.

8 That in about 40 per cent of healthy individuals, who have never had a symptom of eye trouble, there may be some degree of heterophoria for distance, and that, therefore, we should not assume that every patient showing a slight degree of imbalance is, on that account alone, in a serious ocular condition.

The writer states that these conclusions are substantiated by the work of Hansell and Reber, Lucien Howe and the late F. B. Tiffany.

The Power of Adduction or Convergence

The use of prisms, base out, the writer believes is to be condemned as uncertain in giving information on this point. The highest prism adduction obtained by observations of one hundred individuals in perfect ocular health was 26°, the average amount being 14°. The proper method of detecting adduction is to determine the punctum proximum of convergence, which gives the *maximum* of convergence. The familiar dot and line test is recommended, with a measurement of the nearest distance, at which either eye oscillates, or turns out, as the punctum proximum. The writer says that in his experience a *maximum convergence* of 13 metre angles is necessary for comfortable and satisfactory use of the eyes in near work.

The Abduction

The measurement of the abduction by means of prisms, base in, is, on the other hand, free of objections to be made against the use of prisms for measuring adduction. The degree of prism divergence in healthy eyes is said to be quite definitely fixed and as a rule increase of the amount first determined in any given prism is not possible by

further practice with prisms (Duane). The visual amount of abduction in normal eyes is but 7° or one meter angle. The determination of abduction is of use as a guide in conditions of weakness of adduction for, if there is overaction of the external recti, this may be of significance in insufficiency of the interni. Attention is directed to the proposition that prism abduction of less than 7°, in the absence of symptoms of muscular asthenopia, is not to be considered pathologic.

Sursumduction and Deorsumduction

Normally these are of the same amount and about 2° (prism) in amount. Hence, if in a patient there is a decided difference between these functions there may be assumed a definite condition of weakness.

The Condition of Heterophoria with Suggestions as to the Treatment of Muscular Imbalance

Slight or moderate degrees of heterophoria are possible in 40 per cent of healthy subjects. The great majority of these cases are innervational in type. Therefore, in the treatment of these cases proper refractive corrections, including presbyopic findings, should be given.

(a) *Exophoria.* What does the existence of this anomaly signify? Doubt is at once thrown on the function of convergence. The punctum proximum of convergence should be first found; if this maximum of convergence is appreciably below 13 meter angles and if in addition the minimum of convergence should be much above one meter angle, we may suspect an overaction of the e. ternal recti as a complication. As Tscherning says: Insufficiency of convergence "is not in the muscles; it is in the innervation of convergence that we must seek for the course of the deviation." Given such a case of exophoria with insufficiency of convergence, what should we do?

"The refraction should be first corrected as an essential

preliminary step. Next, if the muscular asthenopia continues, we should attempt to secure an improved innervational impulse from the hypothetical convergence center in the brain cortex by exercises with *adductive prisms*, or by other methods calculated to train the adduction. I am opposed to the use of prisms, bases in, to be worn by the patient, and have not prescribed such for many years. This use is unscientific and tends to increase the degree of convergence weakness. If the measures noted are without result in the way of securing relief from the distressing nervous symptoms of this type of asthenopia, then operation is certainly indicated. If the maximum of convergence does not fall below 6½ meter angles, non-operative measures may possibly prove successful. If they do not, however, or if the maximum of convergence is lower than 5 or 6 meter angles, to start with, then operation will be required."

Insufficiency of convergence may exist with an apparent orthophoria or esophoria at distance. The insufficiency is the key to the situation, however, and not the orthophoria or esophoria, for the reason that the esophoria may be pseudo and is to be explained as the result of a constant effort to maintain sufficient convergence to avoid diplopia at the near point, a partially spastic condition of the internal recti muscles being induced. Such a condition does not interfere with the treatment for convergence insufficiency.

(b) *Esophoria*. In the majority of cases this esophoria is associated with accommodative strain, as in hypermetropia, but may be found in myopia or even emmetropia. Esophoria is considered as due to convergence excess (Hansell and Reber), the result of divergence insufficiency (Landolt), and both causes are given (Duane).

"In moderate degrees of esophoria it is probable that accurate correction of the refractive error, if any be found to exist, will be sufficient to relieve the state of muscular imbalance, and such treatment should invariably be used before making any other attempt. If the tendency to

convergence should continue, nevertheless, one must choose between the constant use of prisms, bases out, in combination with the ametropic correction, and surgical interference. No advantage will be gained by exercises with prisms, bases in, to stimulate the power of abduction, and this method is not recommended."

In cases of esophoria of over 6°, it is best to correct half of the esophoria and divide the correction between the two eyes. It is almost certain that the prisms will have to be increased up to the full amount of the esophoria. If the esophoria should be of 10° or more to start with—or increase to that—then operation is indicated in the presence of continued asthenopia.

(c) *Hyperphoria.* In practice we should give our cases, showing a degree of this type of muscular error, a chance to secure proper vertical balance by the use of lenses to correct any existing ametropia before proceeding further.

"We must remember that a spurious hyperphoria may exist, which may disappear after the correction of an error of refraction, or the relief of an esophoria or exophoria. In conditions of hyperphoria amounting to from 4° to 6° this will rarely be found possible. In such cases, in which the asthenopia persists after the correction of the refraction, and where exophoria, or esophoria, is not present, we may assume that the hyperphoria is permanent, and that we will, at least, be forced to make use of prisms vertically placed for constant use. The prism strength should be one half of the manifest hyperphoria to commence with, the prism correction being divided between the two eyes, base down before one and base up before the other. The hyperphoria may in all probability show a constant increase under this use of prisms, requiring a commensurate increase in the prism strength employed." Consideration is given under cover of these headings to operative procedures. A very profitable discussion of this paper is reported in the same issue of the *Journal:* (pages 892-895).

(Abstracted from *American Journal of Ophthalmology*, Vol. 3, p. 878, 1920.)

Professor Arthur Thomson's Theory of the Production of Glaucoma

Jadavji Hansraj Vaidya, D.O.M.S.

AFTER recording his own observations as to the period of day or night in which attacks of glaucoma are likely to occur, the writer refers to the fact that Thomson's views on the genesis of glaucoma (*Ophthalmoscope*, Vol. VIII, p. 608, 1910) affords him a satisfactory explanation. The writer, believing that many European readers are not furnished with this theory, briefly presents it. We in turn present it feeling that many American readers will at least be interested in the presentation of facts of interest and value.

In short, Professor Arthur Thomson has shown that posterior to the opening of Schlemm's canal there is a projection all round from the inner side of sclera. This projection he calls the scleral spur. In longitudinal section it is almost triangular in shape. To its anterior aspect or apex are attached the fibres of the ligamentum pectinatum. This ligament is elastic. To the posterior aspect or base of the spur are attached fibres of the ciliary muscle. During accommodation the ciliary muscle contracts and in so doing it pulls the scleral spur backwards, thereby pulling the walls of Schlemm's canal apart; whilst at the same time the ligamentum pectinatum is stretched. By widening of Schlemm's canal negative pressure is induced in it. This leads to an in-rush of aqueous in the canal from the iridic angle. Then follows the second part of the phenomenon. The ciliary muscle ceases to act. The pectinate ligament by its inherent elasticity tries to return to its normal condition, thereby positive pressure is brought about in Schlemm's canal. The fluid, which rushed into Schlemm's canal during the time the pressure was negative in it, is now subjected to positive pressure. It can no longer return to the anterior chamber as the scleral spur by returning to

its former position closes the passage to the anterior chamber. The fluid can only pass to the anterior ciliary veins. In fact it is pumped on to the veins. This process is repeated every time the accommodation is brought into play; and fluid from the anterior chamber passes on to Schlemm's canal, thereby maintaining equilibrium of intra-ocular pressure.

Now it is quite plain that accommodation acts only during waking hours and it stops during sleep, and hence changes—brought about by the constantly altering conditions of accommodation—are no longer in action during sleep. How is it then that in normal conditions the equilibrium of intra-ocular pressure is maintained? It is possible either that the secretion of aqueous should be enormously diminished or stop altogether or that the work of excretion be carried on through some other channels. So far the physiologists have not proved that the process of secretion ceases during sleep nor have they demonstrated that it is diminished; on the other hand, we have reasons to believe that aqueous is secreted during sleep. The reasons I allude to are first, when a patient is under the effects of an anaesthetic and an incision is made in the cornea, the aqueous flows out, but if some time be allowed to pass the anterior chamber is filled in again. Let it be made clear that normal sleep is not similar in every respect to narcosis produced by an anaesthetic and that the emptying of the anterior chamber induces negative pressure in it and that thereby conditions favourable to the secretion of aqueous are produced which are far from being similar to the conditions in normal sleep. The second reason is that it has been proved that urine is secreted during sleep, and Mr. Treacher Collins has shown that histologically there is a certain amount of resemblance between the ciliary body and glomeruli of the kidneys; and hence it is quite possible that aqueous humour which is secreted by the ciliary body continues to be secreted during sleep. Now, under

these circumstances, as the aqueous which is secreted can no longer pass on through Schlemm's canal during sleep, there must be some other passages through which it finds its way out under normal conditions. We know that there are two routes at least through which the aqueous can find an exit. These are through the crypts of the iris and the posterior route through lymphatic channels of Cloquet's canal.

In normal eyes, or in eyes not predisposed to acute glaucoma, this arrangement works smoothly, but in those eyes that are predisposed to acute glaucoma from one cause or another the comparatively scanty filtration is not adequate till morning hours when the patient wakes and the pumping mechanism can come into play again. As soon as the patient goes to bed the pumping mechanism ceases, aqueous collects in the posterior chamber; perhaps part of it forces its way into the anterior chamber and manages to pass through the crypts and thence to the veins. This inadequate arrangement allows a few hours after sleep to elapse before the effects of increased pressure in the posterior chamber begin to be felt. The increased pressure gives rise to venous engorgement which in turn makes the ciliary body and iris turgid. The iris and lens are pushed forwards and a vicious circle is established.

It may be worth while to mention here that during sleep the pupil contracts, hence this factor can be easily said to have no effect on the condition.

(Taken from *The British Journal of Ophthalmology*, Vol. 5, pages 173-175, 1921.)

A New Photographic and a New Demonstration Ophthalmoscope

Professor J. K. A. Wertheim Salomonson

IN these instruments Gullstrand's principle of the "simplified indirect reflexionless ophthalmoscopy" has been applied.

The general arrangement of the illuminating and the reproducing optical systems of the photographic instrument is shown in Figure 1. This image of the retina formed by the lens in its back focus *a*, *b*, is reproduced in the photographic instrument on the same scale by means of a photographic lens B. An arc lamp K, running on six amperes, is the illuminating source and a condenser C forms an

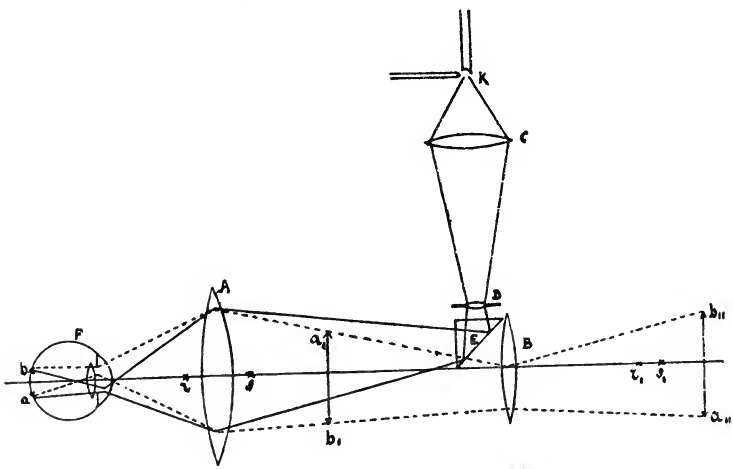
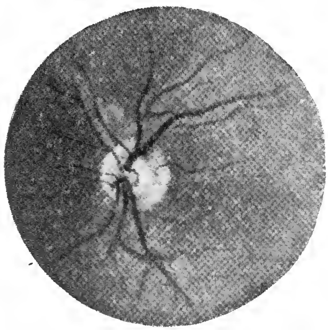


Fig. 1. Diagrammatic sketch of apparatus.

enlarged image of the crater at the diaphragm D. A rectangular prism E placed immediately below it deflects the illuminating rays in the direction of the ophthalmoscope lens, the surface of which is reproduced in the plane of the

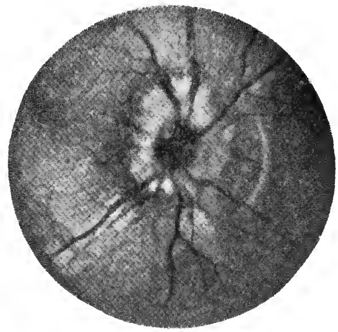
condenser by a lens, resting on the diaphragm, where also the photographic shutter has been placed. The already-mentioned reflecting prism partly covers the front surface of the photographic lens, so as to leave a free surface of a

A



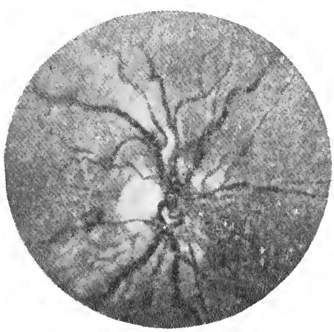
Normal fundus

B



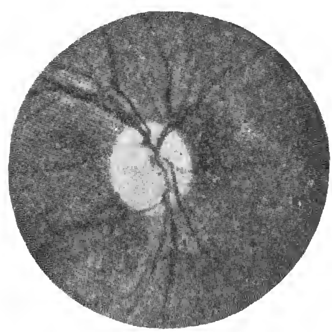
Choked disc in cerebral tumour

C



Choked disc in syphilitic meningitis

D



Atrophy of papilla.

little more than half the diameter of the last one. If the pupil of the eye be placed at such a distance from the ophthalmoscope lens that this reproduces the aperture of

the photographic lens, and, of course, also the illuminated diaphragm in the pupil of the eye, we have fulfilled the condition postulated by Gullstrand for the elimination of the reflexes on the cornea and the eye-lens; provided that in the eye pupil there be a free space of nearly 2 millimetres between the image of the diaphragm and of the uncovered part of the photographic lens.

We now have still to consider the presence of two images *r* and *s* of the illuminated diaphragm formed by reflection on the front and back surface of the ophthalmoscope lens. These images have a great intrinsic luminosity, and would spoil the photographic reproduction of the retina; therefore they must be rendered innocuous. In my instrument this is done by placing two very small blackened screens, of about 1.5 millimetre diameter, exactly in the places *r*, and *s*, when these reflexions are sharply reproduced by the photographic lens. As these screens cause the appearance of a limited quantity of diffracted rays behind them, I had also to reduce the photographic action of the reflected rays by the interposition of a very small yellow transparent screen on the centre of the surface of the condenser. The illumination of the fundus is not appreciably lessened by this screen, whilst the reflexions on the ophthalmoscope lens are practically eliminated.

During the focussing of the retinal image the intensity of the arc light is reduced by a suitable absorbing medium, viz., a smoked and varnished mica-plate. Exposures of about 1/10th to 1/12th second are sufficient to give excellent negatives on panchromatic plates. They easily bear a direct enlargement of about two times. Having a diameter of 40 millimetres, they show the fundus over a solid angle of 30° covering a little more than five times the diameter of the papilla nervi optici. For taking photographs the pupil ought to be dilated to at least 7 millimetres.

In the demonstration instrument a small one-half watt lamp absorbing about 10 watts is used. A short telescope

replaces the camera and photographic plate. In order to eliminate the reflexions on the ophthalmoscope lens, the light from the lamp passes through a small achromatic double-refracting prism; a very narrow slit which serves as a diaphragm allows only the rays of one of the two images of the glowing filament to pass through it. These rays are polarized, and the reflected images of the diaphragm consist of polarized light. In the fundus the light is de-polarized. As the telescope contains a small Nicol prism the reflexions can be extinguished, whereas the retinal image remains visible. The magnification of the telescope can be varied by using different eyepieces. The absolute magnification of the retina can in this way be varied from 6 times to about 50 times. Generally a magnification of 14 times is used, giving nearly the same vision as in indirect ophthalmoscopy. The field is a little less extensive than with the photographic instrument, and covers nearly 28°. Of course with the strongest eyepiece the field is much narrower, and with the strongest eyepiece we can just cover the papilla nervi optici. The light is quite sufficient even with this strong magnification; it is about 10 times stronger than with the large Gullstrand ophthalmoscope, so as to render the use of strong eyepieces of practical advantage.

The greatest advantage of the instrument is that we are able to place it before the patient so as to render the image of the retina immediately visible to anyone looking into the instrument, even if he has not the slightest notion of ophthalmoscopy. The image needs only focussing, which is done by a slight movement of the eyepiece.

(Abstracted from *The British Journal of Ophthalmology*, Vol. V, p. 163, 1921.)

Asthenopia

Edward Jackson, M. D.

THIS word was defined by Mackenzie as "that state of vision in which the eyes are unable to sustain continued exercise upon near objects," without other evidence of disease. Many cases were removed from this class by Donders' observations regarding hyperopia, astigmatism and presbyopia. It may now be held to include only those unable to use their eyes for more than a very brief time without pain, although the eyes are without recognizable ocular conditions to account for this disability. Sufferers from asthenopia in this sense are always something of a puzzle to their medical advisors. There is a tendency to doubt if the suffering so much complained of can be wholly real, and not more or less exaggerated.

It must be borne in mind that we have no common unit for suffering; no objective method of measuring it, except by the evident effects it produces on the sufferer. That different persons suffer very differently, from exactly the same injury or lesion, must be admitted by every observing physician. The same person differs enormously in sensibility to pain, in different physical conditions. A college professor known to his friends as a nervous man, with little stoic endurance of discomfort, when living his routine working life, became a different individuality during his summer vacation. After a few weeks cruising on a sail boat, he suffered a carbuncle involving most of one side of his face. He opened it freely himself, with the knife he carried; and said this was no worse than skinning his knuckles when at home. The extensive facial scars resulting became as much a matter of pride as those of a German college duellist.

We must judge of suffering by the testimony of the sufferer. Although one is sometimes tempted to indulge in skepticism about it, this is the only evidence we can get

on the subject; and to form any rational judgment we must consider such evidence. Judged by such evidence, asthenopia is a morbid condition worthy of our best efforts to relieve. The fixed idea that all such complaints are "hysteric" and must be ignored, is irrational and quite fatal to the usefulness of the physician.

Among the forms of asthenopia that get scant attention and little sympathy, at least in temperate climates and among city dwellers, is that of pain produced in apparently normal eyes by exposure to bright light; although everyone admits that this is to be expected in eyes that are suffering from certain ocular inflammations. We recall a sufferer from such asthenopia in the medical corps of the navy, who for years had been regarded with suspicion by his superiors, and given scant consideration because his eyes exhibited no objective lesions; and he was suspected of simply trying to avoid duty at sea and in the tropics.

Under the name "tropical asthenopia" this disability is given the consideration it deserves by Col. Elliott in his recent book, *Tropical Medicine.* He brings together the following instance in support of the reality and seriousness of the affliction. "A young English planter in the East travelled many miles to consult a surgeon. A 'careful examination' of his fundus was made, and he was assured that there was 'nothing the matter with his eyes.' Some idea of the despair into which the loss of his last hope plunged him, may be gathered from the fact that he returned to his estate and drowned himself. The medical man, whose 'careful examination' had probably increased his patient's suffering, was disposed to consider the patient's symptoms unreal, until he heard of the melancholy ending of the case. It was only then that he realized that possibly he had made a mistake—an opinion in which there was little difficulty in confirming him.

"A gentleman who had served a long time in India complained that, in his worst attack, which, by the way,

was cured by leave to Europe, he was so bad that, when he was on his journey home, the 'sight of a white face was enough to pain him.'

"A medical man who suffered from glare, stated that on one occasion when he went home much run down in health, it was painful for him to write on white paper.

"An elderly gentleman in the Civil Service only began to experience any trouble in the last four years of an exceptionally busy and active official life in India; his servant had orders to enter his room before daylight, to close every door and window, as otherwise the light was apt to upset him for the day.

"An ophthalmic surgeon in large practice suffered so severely from his eyes that he had to devote Sundays to lying in a darkened room, in order to rest himself sufficiently for the work of the coming week. He was only able to carry on by the determination 'to stick to it' at all costs.

"A missionary who had landed in India full of enthusiasm, was seen in a condition bordering on insanity; he said that life was one long misery; even in the dark room the least ray of light annoyed him. An Ichabod had been written across his once ardent missionary zeal, and his one desire was to obtain a medical certificate that would enable him to escape from 'this hateful glare.' "

The importance of asthenopia has frequently been forced upon the writer by the extreme cases that occur among patients suffering from pulmonary tuberculosis, involving lesions of considerable extent, but generally with rather good systemic resistance. Such patients sometimes have marked errors of refraction and sometimes very slight ones, but no evidence of ocular disease. In either case they complain of very slight inaccuracy in their correcting glasses, and appreciate some diminution of suffering from slight rectification of their lenses. But they never get anything like complete relief from their pain and disability, and under

the best possible conditions cannot use their eyes anything like as much as they wish. With recovery from the tuberculosis, they become free from asthenopia, and may discard glasses on which they were before entirely dependent.

All who make a practice of carefully correcting errors of refraction find a certain number of patients whose suffering is not relieved by lenses. Attention to muscular imbalance relieves some others, but some remain who are no more helped by that. A few minutes' use of the eyes provokes the pain; from which they have vainly sought relief from various physicians, and from various current systems of medical quackery.

Pain is "the tongue of disease" in which effective protest is made against some overstepping of the limits of endurance, by departures from the conditions of healthy living. It only becomes effective after a long period of struggle against some adverse influence, and depends but little on the temporary condition that seems to give rise to it. The tropical asthenopia does not arise from seeing a white face, or ten minutes' exposure to the morning sun; but from the ten years' unnoticed struggle, against what was for that particular organism an adverse influence of vital importance. This may have been excessive light; but it may also have been excessive heat, and other altered conditions of living that finally produce a form of asthenia that leads the body to react by pain, to what was once a normal stimulus.

Much the same is true of the consumptive. The long saturation of his nervous system by the toxins of the tubercle bacillus, while stimulating it to a reaction needed to combat the invasion that threatens the body's destruction, has also come to limit by pain the demands made by even the slight mental and physical effort of reading. Presumably, this is in the interest of the conservation of nerve force, or the equalization of the circulation demanded in combating the bacillary invader. Unquestionably other persistent

infections lead to a similar result as in the headaches of chronic appendicitis.

Careful analysis must be made of the life of the asthenope, who is found in the residue of patients unrelieved by lenses, prisms or exercises. This analysis, differing from the psycho-analysis of Freud, so effective in some cases of "hysteria," but which might be compared with psycho-analysis, will sometimes show us the deep-lying unobtrusive, but long acting causes of his asthenopia, in the patient's previous life.

These patients are generally adults, often nearing middle life, or older, whose habits of nerve action and reaction have long been formed and are well established. Any rehabilitation to be effective must be founded on investigation and inference, going deep and extending far back, and on changes in the habits of using the eyes, or rather the portion of the central nervous system exercised by use of the eyes, which must be persistently insisted on until new habits and reactions are established, at a period of life when they develop very slowly.

A good intellectual appreciation of the essential basis of asthenopia, and the difficulties of removing it, should be followed by a frank discussion of the situation with the patient. These patients have generally been disappointed so often that they are not much disturbed by the lack of any promise of quick and easy relief; and nothing but the patient's intelligent, persistent coöperation, in living and working along the lines indicated for his or her particular case can ever effect a cure.

(Reprinted from the *American Journal of Ophthalmology*, Vol. 4, p. 218, 1921.)

The American Journal *of* Physiological Optics

125

Pupillary Phenomena*

Thomas Hall Shastid, A.M., M.D., F.A.C.S., LL.D.

THOUGH much ignored, the position, size, shape and color, as well as the various reflexes and associated movements of the pupils, are extremely important both for the specialist and the general practitioner. With this fact I was, in my earlier days, very deeply impressed. A physician, aged 65, suddenly and without apparent cause became seemingly insane. For minutes at a time, especially if addressed by other persons, he would be as rational as anyone. Then he would start talking absurdly, point to non-existing objects, and allude to non-existing sounds. This condition had persisted for some days or weeks. Doctor after doctor pronounced the physician a lunatic. A few consultants demurred, without, however, presuming to proffer any other diagnosis.

The case was sent to Dr. Janeway, in New York, who proceeded to make the examination with his characteristic caution. In the midst of his observation of the pupils, he stopped short, and cried: "What drugs has the man been taking?"

"Nothing but a little bromide."

"Strip him."

The man was stripped, and, in a trice, the able diagnostician had removed from the patient's back a number of belladonna porous plasters.

*Read before the Head-of-the-Lakes Optometric Association, May 15, 1922.

The skin was washed, and in a very few hours the patient was absolutely well. He had been suffering from chronic belladonna poisoning, and his story was written plainly in the pupils of his eyes.

The pupil is the hole in the doughnut, and we cannot speak at all of the hole without some kind of reference to the doughnut upon which the hole depends for its existence. The doughnut is the iris. It contains two antagonistic muscles, the *sphincter pupillae*, or circular fibres, and the *dilator pupillae*, or radiating fibres. The sphincter is supplied (actuated) by the third cranial nerve, also called the *motor oculi*, because it supplies the muscles of accommodation and nearly all the extrinsic muscles of the eye, as well as the contractor muscle of the pupil. The dilator of the pupil is supplied by the sympathetic nerve.

We can have no sort or kind of understanding of the pupil unless we clearly know (at least in outline) the nervous mechanism whereby the numerous movements of the iris (thereby of the pupil also) are produced.

To begin at the beginning. The retina does not throughout its whole extent consist of visual (seeing) fibres only. In and about the macula there are, in addition to the seeing fibres, other fibres called "pupillomotor fibres." The area in which the pupillomotor fibres occur is very small, certainly not more than 3 mm. in diameter. Some of these pupillomotor fibres are responsive to light (photo-responsive) others to darkness (scoto-responsive). When any change is made in the intensity of the illumination falling upon this, the pupillomotor area of the retina, a change occurs also in the size of the pupil. If the illumination is increased, the pupil, through the photo-responsive fibres, becomes smaller. If, however, the illumination be diminished, the pupil, through the scoto-responsive fibres, is made larger.

How are these effects of light and shadow on the size of the pupil produced? Let us consider first a pupillary contraction. The quantity of light, falling on the pupillomotor

area in and about the macula, is increased. The photo-responsive class of the pupillomotor fibres in that area are stimulated.[1] The impulse runs along these fibres from the macula to the optic nerve. It follows the same fibres into the nerve, and so on to the optic chiasm, where the fibres undergo partial decussation (crossing). Hence it proceeds from each eye (owing to the decussation) to the optic tracts of both sides, and at length it reaches the pupillary contraction center in the floor of the aqueduct of Sylvius—which is simply a passage connecting the third with the fourth ventricle of the brain. In this center the "reflex" (which means simply "bending back") of the nerve current occurs. That is to say, the nervous impulse, or current, is bent back from the center in the brain, not to the point of origin of the impulse in (or near) the macula, but along the third nerve to the circular fibres of the iris, which, actuated by this impulse, then contract, and so produce the narrowing of the pupil. The whole nervous path is called the pupillary-reflex-contraction arc.

Let us now consider a pupillary dilation. A diminished quantity of light falls on the pupillomotor area of the retina. This stimulates the scoto-responsive (darkness-responsive) fibres in that area.[2] The impulse travels along the fibres to the optic nerve; it follows the same fibres within the nerve till it reaches the optic chiasm. Here, like the visual and the photo-responsive fibres, it undergoes a partial decussation. Hence it proceeds from each eye (owing to the decussation) to the optic tracts of both sides, on to the medulla oblongata, and so into the spinal cord, which it traverses throughout the cervical portion of that structure, and on into the dorsal portion thereof, as far as the third dorsal vertebra. At this point seems to be situated the dilation center for the pupil.

[1] The scoto-responsive fibres are at the same time released from stimulation—a matter into which, for simplicity's sake, we do not here enter.

[2] The photo-responsive fibres are at the same time released from stimulation—a matter into which, for simplicity's sake, we do not here enter.

This center is also called the "cilio-spinal center," or "center of Budge." It is at this center, of course, that the "dilation reflex," or bending back of the dilation nerve-current, occurs.

The current then leaves the spinal canal by the ventral routes of the first, second and third dorsal nerves. It reaches the inferior cervical ganglion of the sympathetic, in the lower part of the neck. Then it goes to the superior cervical ganglion, which lies in the neck near the angle of the lower jaw. Thence it passes on into the brain cavity again, together with the internal carotid artery (the great arterial supply to the brain), and thence into the orbit and so on to the dilating muscle of the iris. "A very roundabout road indeed," you will say, and properly. Yet I have greatly simplified my account of the road. We ought, at all events, to remember that the eye, properly speaking, does not reside merely in the orbit, or eye-cavity of the skull. It has its location also in the brain, in at least a third of the spinal cord, then in the lower portion of the neck, again in the upper portion of the neck near the angle of the lower jaw, again in the brain-cavity of the skull, and, once more and lastly, in the orbit. Bear in mind, we are not talking about matters in some way connected with the eye, or about organs which are capable (when themselves diseased) of producing diseases in the eye. We are talking about the eye itself. The eye is a very extensive organ, located not only in the orbit but also in the cavity of the skull, the spinal canal, and throughout almost the entire course of the neck. Is it any wonder that neck injuries and neck tumors produce, for example, one-sided abnormal dilation or contraction of the pupil on the corresponding side.

So much by way of prelimination. Now for the pupillary phenomena themselves. These I classify under six heads: position, contour, size, color, reflexes, associated movements.

Position

The pupil is normally seated not exactly in the center of the iris, but a little to the nasal side. You can easily see the purpose for which the pupil is set to the nasal side of the center. The eyes, when in use, are always converged, at least a very trifle, even when directed at the most remote objects. The pupil is therefore placed to the nasal side of the anterior pole of the eye, and the macula to the temporal side of the posterior pole. In addition, the pupil is generally displaced a very little downwards. The purpose again is obvious. Our eyes are almost always directed a little down, as well as in.

Sometimes the pupil is abnormally and congenitally displaced from the center. It may then be displaced too far in and down, or just too far in or just too far down, or even above or to the outer side of the iris center.

The margin of the normal pupil, or rather the pupillary border of the iris, rests, when the pupil is contracted, on the anterior surface of the lens. When the pupil is dilated, it hangs free in the aqueous humor. The importance of these facts is very great. In iritis (inflammation of the iris), if the pupil is not properly and promptly dilated with some drug, and kept dilated throughout the course of the disease, the iris grows fast to the anterior surface of the lens—a condition which entails the most serious consequences.

Contour

The pupil of a human being is, by nature, round, except in a very few cases. Sometimes it is divided into two or more compartments, there being then what is called double, or multiple, pupils. If the border of any pupil be carefully looked at with a lens, it is seen to be not absolutely smooth, but very finely crenated, *i. e.* notched. So the pupil, after all, is not really round. In some persons the pupil is greatly extended, or elongated, at its lower part. This is a congenital anomaly known as "coloboma" ("defect") of the

iris. The pupil is then either U-shaped or pear-shaped. The elongation is oftenest down and in, but it may be straight down, or down and out. There is another kind of coloboma of the iris, very often seen after cataract operations. In some cataract operations the iris is not cut, but in others (for a reason) a piece of iris is removed. The resultant elongation of the pupil is always upward — not down, or down and in, or down and out — as is almost always the case in the congenital coloboma. A similar defect, or gap, in the iris is often produced by the surgeon for the relief of the terrible condition known as "glaucoma."

There is yet another coloboma to be considered. This is the kind produced by the surgeon for optical purposes only. Let us suppose that an eye has an opacity of the cornea directly in front of the pupil, and that the opacity is of such a density and extent that the patient cannot see with that eye, while some other portion of the cornea remains transparent. The surgeon then cuts out a piece of the iris so as to extend the natural pupil in a direction opposite the transparent portion of the cornea, and tattoos the cornea opposite the natural pupil. The patient then does his seeing *via* the "artificial pupil," as it is called. Needless to remind you gentlemen that the light passing through this eccentrically situated pupil casts its image on the macula lutea almost exactly in the same place as did the light which passed through the natural pupil. Of course it does not make, generally speaking, as sharp a picture at the macula as did the light through the natural pupil, because of aberration in the peripheral portion of the lens, which portion it is that the light now traverses. When an ulcer of the cornea perforates, allowing the aqueous to escape, the iris not infrequently falls into the hole and heals there. Of course there is then also an irregular pupil.

Iritis, too, is often responsible for irregularities in the pupillary contour. Even after iritis is cured, the pupil may still be irregular in shape, owing to adhesions which

have formed between the posterior surface of the iris and the anterior surface of the lens. Such adhesions are called "posterior synechiae," by way of distinction from "anterior synechiae"— the kind resulting when the iris becomes adherent to the cornea after a perforation of that structure either by ulcer or by injury. Certain other abnormalities of the pupillary contour possess an unusual interest. We have in mind those changes in the pupil produced by paralysis of the peripheral branches either of the third nerve (that which supplies the sphincter of the pupil) or of the sympathetic (that which supplies the dilator of the pupil). It will be remembered that we traced the pupillary contraction arc from the pupillomotor area in and about the macula on through the optic nerve and to the reflex center in the brain, where the current is "reflexed," or "bent back," and so on down the third nerve to the sphincter muscle of the iris. It will also be remembered that we traced the pupil dilating fibres from the same area in the retina into the optic nerve, onto the brain, then away down the spinal cord, where it reached the reflex center, then out of the spinal canal by way of the first, second and third dorsal nerves. Thence into the cervical ganglia of the neck, then *via* the carotid canal back into the skull cavity, and so on into the orbit and to the dilator (radiating) muscle-fibres in the iris. Now these dilator fibres are supplied, at the very last, by means of two small nerves, not one single one. The first of these small nerves supplies the upper and outer half of the iris; the other, the lower and inner half. A lesion of any sort, say a syphilitic deposit in the first of these branches, causes paralysis of just half the dilator fibres of the iris. In other words, the pupil, under ordinary illumination, is, in such cases, decidedly flattened either above and outward or else down and inward, according to which of the two nerves supplying the dilating fibres of the pupil has been paralyzed. If the trouble is back of the point of division of the nerves, of course the trouble will affect

the iris all round its circumference, so that, by noting the shape of the pupil, you can tell precisely where the difficulty lies.

Now there is also a change in pupillary shape which is due to paralysis of the peripheral fibres of the third nerve — those fibres, that is to say, which, at the last, supply the sphincter of the iris. These nerves are not two in number, but very numerous, and, according to which of them are affected, the pupil will be changed in one part of its contour or in another, and throughout a greater or a lesser arc, according to the number of fibres affected. If just half the fibres are affected, and these should happen to be the half supplying the upper and outer part of the iris, or the lower-inner part, a condition would result which, at first, a person might suppose would greatly resemble that produced by paralysis of one of the two nerves supplying the dilator. The two conditions, however, can easily be distinguished. If the trouble is in one of the dilator nerves, the affected part of the pupil is flattened; if it is in the contractor nerves, then there is arching instead of flattening. Also, in paralysis of a dilator nerve, strong light obliterates the flattening, makes the pupil good and round. If, however, the trouble is due to paralysis of half the contracting nerve fibres, then strong light exaggerates the arching.

Both the conditions can be distinguished from the alterations of pupillary contour produced by posterior synechiae. Any portion of the iris bound down to the lens by adhesions is absolutely immobile either to the strongest light or the greatest degree of darkness.

Size

The size of the pupil varies greatly according to many circumstances. In infants the pupil is small in order to protect the deeper structures from excessive light. In youth and adolescence it is large. In middle age it possesses a medium size, and, in senility, it is very small indeed. The

pupils are enlarged by anger, fright, and nearly all emotions. They are small in quiet contemplation, large in profound thought. They are larger than normal in myopia, abnormally small in hyperopia. They are extremely small during sleep. When waking occurs, they first enlarge to wider than normal, then contract again, again dilate, and so on till the subject is fully awake. Any person shamming sleep can easily be detected by remembering these facts. He cannot voluntarily cause his pupils to go through those alternate dilations and contractions. Many drugs dilate the pupil, notably belladonna and its active principle, atropin, as well as the very commonly employed derivative of that alkaloid, homatropin. Eserin, pilocarpin and some other substances contract the pupil. Many drugs affect the pupillary size when taken internally. Thus, opium and its derivatives (morphin, codein, etc.) contract the pupils strongly. Belladonna, stramonium and some other drugs, taken internally, produce pupillary dilation.

The pupil, as everybody knows, contracts to light and expands to darkness. A fuller consideration of these phenomena will, however, be presented under the heading, "reflexes."

The pupil contracts also during accommodation and during convergence. It then as a matter of course expands as convergence and accommodation relax. A fuller consideration of these phenomena will be presented under the heading, "associated movements." We may here, however, properly emphasize the fact that the contractions of the pupil during accommodation and convergence are not "reflexes," but "associated movements."

Enlargement of the pupils occurs in many diseases and states produced by diseases. Of these the following are commonest: Total blindness from any cause whatsoever; glaucoma; and obstruction to the nerve current anywhere throughout the pupil-contraction path from its origin in and about the macula to its termination in the contractor muscle of the iris, as well as any irritation anywhere in

the pupil-dilation path. Fainting, insanity, and many other general conditions also produce it. Contraction of the pupil, on the other hand, results from any irritation of the pupil-contraction path from its origin in and about the macula to its termination in the dilator muscle of the iris, as well as any obstruction in the pupil-dilation path. A goitre, by its presence in the neck, very often produces either contraction or dilation of the pupil on the side whereon the goitre is largest, according to whether the pressure is only enough to irritate or is sufficient to paralyze.

Unequal pupils, *i. e.*, pupils of differing widths on the two sides, are not so uncommon as careless observers would suppose. Nor are they quite so indicative of terrible conditions of the nervous system as was once believed. Among healthy medical students, anisocoria (unequal pupils) were found in ten per cent of a very large number examined. Anisocoria, when really significant of serious disease, often means insanity. It is frequently caused by suppurating teeth or tonsils, or by pus in some of the accessory sinuses of the nose.

I cannot, in the course of so brief a paper, stop to indicate all the practical applications of the various phenomena which I mention. I must, however, at this point, insist upon the extreme importance to a refractionist of the size of the pupils. For example: Ordinarily we do our distance testing at 20 feet. And we are accustomed to say that rays of light which leave a single point 20 feet away, and which, on reaching the eye, have not diverged more than the width of a pupil, are to all intents and purposes parallel. Now, the truth is that they are not to all intents and purposes parallel. The error involved amounts, in an average case, to a +0.17 D lens placed in front of the eye. Such a lens makes the twenty-foot rays not approximately or substantially, but actually, parallel. The practical consequences[3] are that,

[3] These practical consequences I have not seen elsewhere adverted to. Hence the space which I have given to them here.

[Note by EDITOR: See the article on *Some Points in Handling Cases of Presbyopia and Subnormal Accommodation* in this issue of the *Journal*.]

in a hyperope, the full correction is +0.17 D too great; in a myope, 0.17 D too little. In the case of the myope, the error does not specially matter, because, ninety-nine times in a hundred, a myope, even with his distance glasses on, is looking at some point well inside of 20 feet, and, so doing, is simply relieved of 0.17 D strain on his ciliary muscle, while still his vision is perfectly corrected for the distance of the object which he has in view. In the hundredth situation, however — *i. e.* when the myope is looking farther than 20 feet, then he does not see with quite the maximum distinctness. The difference, however, is very slight, and he does not as a rule take note of it. Of course, if a patient wants distance glasses to enable him to see with maximum distinctness while on an automobile trip, and his error at 20 feet is —0.88, we should not hesitate at all to give him a whole dioptre. Even then he would be undercorrected by just 0.05 D.

But, in the case of a young hypermetrope, the matter stands different. Hypermetropes past forty years of age, it is true, do not, as a rule, resent a trifling overcorrection. Such an overcorrection, as a rule, tends to relieve their failing accommodation, which enjoys a little relief even at other distances than that for reading. But overcorrect a young hypermetrope, in whom the ciliary muscle is almost invariably active, and you land at once in trouble. You must cut off that 0.17 D of overcorrection which is produced by the substitution of 20 feet for infinity. Unable to do this exactly, because, in our system of numbering lenses, we do not have any intervals of 0.17, we cut off instead that which is nearest to it, which is generally 0.25 D.

Now here comes in the great importance of the pupillary width. The overcorrection of hypermetropia and the undercorrection of myopia, resulting from the substitution of 20 feet for infinity, amounts to exactly 0.17 D only on the supposition that the pupils are of average width. But, if the pupil is very wide, the error may amount to 0.25,

even to 0.35, of a dioptre. You see how far astray you may be put by merely a wide pupil. On the other hand, a narrow pupil means less error.

All this has nothing whatever to do with the peripheral aberration of the lens, which is also, by wide pupils, allowed to come into play and so to complicate the situation further. It only deals with the errors involved in regarding 20 foot light as coming from an infinite distance.

Now let us consider, for a very little time, the trouble which is caused in refraction work by larger or smaller pupils, in the way of permitting, or excluding, the peripheral aberration engendered in the non-central portions of the lens.

You all know that wide pupils, even in emmetropes, mean diffusion circles on the retina. You also know (as above expressly stated) that myopes have generally pupils of unusual width; hypermetropes, on the other hand, pupils of unusual narrowness. And yet, too, hypermetropes are often afflicted with large pupils. Now, why, as a rule, do hypermetropes have small pupils? Because of the excessive accommodation they employ in the endeavor to overcome their hypermetropia. Increased accommodation, as we shall see hereafter, means, in association with it, narrowing of the pupils. Similarly, myopes have large pupils because of the continual endeavor they are making to relax accommodation and so to lessen the myopia. But, aside from these accessory causes, some people have, whether myopic, hypermetropic, or emmetropic, very large pupils or very small ones, just as some people have large hands or feet, or large mouths or small ones. Now, whether in myopes, hypermetropes or emmetropes, large pupils mean diffusion circles on the retina, and these diffusion circles may, of and by themselves, cause not only blurry vision, but also and independently of any error of refraction, much suffering.

That is why many an emmetrope comes to you apparently suffering from refractive asthenopia. His pupils are too large, at least indoors. If he walks outside, his pupils

contract and he is at once free from distressing symptoms. A weak solution of eserine will keep him comfortable indoors also, but just so long as he keeps using it.

The small-sized pupils of outdoor people also explain why this class do not as a rule appreciate the correction of even fairly high degrees of hypermetropia and astigmatism. Their irides and pupils are, in effect, pinhole discs, throughout the most of their existence.

The large diameter of the myope's pupils explains why the myope has a way of squeezing his eyelids together. In this manner he lessens at least the vertical diameter of his pupils, and secures sharper vision. Be sure not to let him do this while you are testing him.

There are two further very important, and often seemingly mysterious, facts which are easily explained by the same simple matter of pupillary size. I refer, first, to the fact that some myopes get a great deal of relief from asthenopic symptoms by means of a very low sphere, say —0.25; second, to the fact that some hypermetropes get little relief from their asthenopia, no matter how carefully they have been refracted. Both these classes of patients have large pupils. Now, it is a fact already known to you that a plus lens, while it diminishes the central diffusion (that produced by the hypermetropia) actually increases the peripheral diffusion (that produced by the peripheral aberration of the lens of the eye in the presence of a large pupil). Hence, in such cases, the relief produced by the correction of the hypermetropia of the central portion of the lens is more or less counterbalanced by the extra suffering induced by the increased amount of peripheral aberration.

On the other hand, a minus lens not only diminishes the central diffusion in the retinal image (that caused by the myopia) but it also lessens the peripheral aberration produced by the extra width of pupil so often present in myopia. Hence the great relief which is occasionally experienced

even at the near point by a megalocoric (large-pupilled) myope from the wearing of a very low sphere, say —0.25. I insist upon this matter especially, because a great many refractionists do not believe it necessary or proper to correct very low degrees of myopia, especially for reading. Before you decide, look to the width of the pupils. I would gladly say a great deal more about the importance of pupillary width in the work of the practical refractionist, but must hasten on.

Color

The pupils vary in color from infancy to old age. The blackest and clearest are in infancy. The older the subject, the lighter and more misty the pupil. The pupil may be obscured by the presence in it of pus, or exudate, as in iritis. It is sometimes reddened in hemorrhage from the iris or ciliary body. The color is grayish, whitish or reddish, in cataract, except in black cataract, when the color may be very little altered if at all. In tumors of the fundus, especially retinal glioma, the color of the pupil may be very much changed, actually presenting in glioma, a whitish, even a dazzling, appearance.

Reflexes

The most important reflexes of the pupil are those produced by light and by darkness. We have already learned by what a complex mechanism the pupil is widened by darkness and contracted by light. The coarser fibres of the optic nerves are those whereby the size of the pupil is regulated; the finer and far more numerous fibres are those for vision.

Now each of these functions, the darkness-reflex and the light-reflex, operates in two very distinct manners — directly (when the increase of light or darkness is allowed to fall upon the eye whose pupil is being observed) and the *indirect*, or *consensual* (when the increased light or darkness

is allowed to fall upon one eye while the effect thereof is watched in the pupil of the fellow eye).

As to the manner in which the direct light-reaction should be tested, I quote from my own book, "*Ophthalmic Jurisprudence*," page 54: "The patient, by ordinary diffuse daylight, is caused to face a window, and to gaze at a distant object, the while he holds a hand across the eye that is not under examination, in order to exclude the light therefrom. The examiner then first notices the size of the pupil in the eye that is being tested, and then excludes the light therefrom (by holding a hand across it) for as long as five or six seconds. On removing his hand, the examiner will find, in case the light-reflex is normal, that the pupil has considerably enlarged. The enlargement, or dilation, remains for about half a second, and then is followed by a very decided contraction. This contraction is succeeded by a moderate dilation, and that by a still more moderate contraction, until at last the pupil becomes stationary in a condition of more or less moderate contraction, according to the intensity of the illumination. By the rapidity and the amplitude of these pupillary excursions the examiner decides whether the light-reflex is normal or abnormal.

"All the conditions of the test, however, as above laid down, should be carefully complied with. Thus, if the examinee stands with his back, instead of his face, toward the window, the illumination may not be sufficient to affect the pupil visibly, even if the light-reflex be normal. Again, if the eye that is not under examination be not excluded from the light, the illumination that enters that eye will affect the pupil of the fellow organ through the 'consensual' light-reflex. Still further, if the examinee's gaze be not directed at a distant object, then the contraction of the pupil which results from, or at least accompanies, convergence and accommodation, will suffice to confuse the examiner."

The indirect, or consensual, reaction is taken as follows: Leave uncovered the eye whose pupil is to be watched.

Cover the fellow eye for five or six seconds. Then remove the hand from before the fellow eye, and the pupil of the eye that is being watched, although already contracted because exposed to light, will contract still further. You see that, in the reflex centers of the brain and spinal cord, there exists a communication across from the centers for one eye to those for the other. Hence the light impulse, or the darkness impulse, when it reaches the center in the brain or spinal cord, is not merely bent back ("reflexed") to the contractor and dilator-muscles of the iris of the eye the impulse came from, but part of it passes over from the brain or spinal center for that eye across to the brain or spinal center for the other eye, and so down to the muscle of the other eye, as well as to the eye that the impulse came from[4]. The reflex that goes back to the same eye is called the "direct," that running across to the center for the other eye and then down to the muscle of the other eye, the "indirect," or "consensual" reflex. The "consensual" contraction or dilation is never so extensive as the direct, but it bears (as I have shown) a greater proportion to the direct when made by low than when made by high illumination, also in the young than in the old.

One of the commonest uses of the pupillary light reflex test is the unmasking of pretenders. A person professes to be blind, either to secure damages after an accident or to escape the military draft or for some other reason. If the pupils act quite well to light, the claimant is almost certainly "putting on." Not necessarily, however, for, if the injury or disease be located higher up in the visual fibres than the corpora quadrigemina, then the patient will be blind, and yet will have his normal light and darkness reflexes. The visual fibres and the pupillomotor fibres run together from the eye until they reach the corpora quadrigemina. Here they part company, and go their separate

[4] The consensual reflex is also partly due to the crossing of the fibres in the optic chiasm.

ways — the visual fibres to the occipital lobes of the brain, where the centers for sight are located, and the pupillary fibres to the center for the light reflex in the aqueduct of Sylvius and to the center for the darkness-reflex in the spinal cord, according as these fibres are light-reflex fibres or darkness-reflex fibres. So you see that, between the eye and the corpora quadrigemina, where the visual fibres and the pupil fibres part company, an injury or disease producing blindness will necessarily affect both the fibres for sight and the fibres regulating the size of the pupils. Beyond the corpora quadrigemina either the sight alone will be affected, or the pupillary contraction or pupillary dilation alone.

You have all heard of the Argyll Robertson pupil. (By the way do not write Argyll Robertson with a hyphen, as is very commonly done. Only one man discovered this sign, and his surname was Robertson. He had not a compound surname. One of his Christian names was Argyll.) The Argyll Robertson pupil is a pupil which does not respond either to light or to darkness, but which does contract to increased, and dilate to diminished, convergence. Instead of "convergence" it is customary to say, "accommodation." But if, in these cases, +4.00 D lenses are placed in front of the eyes, and then the patient changes his gaze from a far point to a near one, the pupils contract, although there has been no increase of accommodation. If, on the other hand, prisms of sufficient strength, bases in, are placed before the eyes, and the patient alters his gaze from far to near, no pupillary contraction takes place.

The Robertson pupil (as it is better called than the Argyll Robertson) is very important, because it is commonly present in the early stages of tabes, *i. e.* locomotor ataxia. It helps, therefore, to make an early diagnosis. It is also often present in the disease called paresis, but in that disease the pupils are much more apt to be unequal in size. Moreover, in paresis, the Robertson pupil is generally

transitory. This pupil also occurs in paralytic dementia, multiple sclerosis, and injuries of the spine.

The "pain reflex," also called the "sensory" reflex, consists in a dilation of the pupil produced by pinching, or painful pressure, in any portion of the body. It is useful chiefly to neurologists.

Another important reaction is the Gallassi-Gifford reaction. This consists in a contraction of the pupil whenever the subject attempts to close his eyelids forcibly. To bring it out well, the observer should spread, or hold, the lids apart with speculum or retractors, and then have the subject of the experiment attempt to bring the lids together. At each attempt, the pupil will be seen to contract. This is a perfectly normal reflex. It is used chiefly to determine whether the sphincter muscle of the iris is paralyzed, and is therefore exceedingly valuable in cases of belladonna poisoning—for example, the case I mentioned at the outset of this paper. Belladonna paralyzes the sphincter muscle of the iris, as well as stimulating the dilator. The contractor muscle, therefore, in belladonna poisoning, will not react to the strongest attempt of the patient to close his eyes against the resistance of the retractors. The same condition, it is true, can be due to a lesion of the short ciliary nerves — those, namely, running between the ciliary ganglion and the contractor of the iris, but this would have had to occur on both sides, right and left, in order to simulate belladonna poisoning. Even then there would be no delirium. Inasmuch as, in the case above-mentioned, there had been no drug administration known to the attendants, and yet the poisoning was continuous over many days, the inference of belladonna porous plasters was inevitable.

Budge's reaction is simply an imagination reflex. If the subject thinks of darkness, his pupils dilate; if he thinks of light, they contract. These reactions are present only in strongly imaginative persons.

Paradoxical light and shade reflexes are those which, on

increased or diminished illumination, are just the reverse of normal. The pupils, that is to say, are contracted by the dark and dilated by the light. These reversed light and shade reflexes occur only in certain nervous diseases — hysteria, tabes, paresis, dementia precox.

Associated Movements

These are often classed with reflexes, but they are not, in any proper sense, reflexes. Let us consider a similar matter by way of illustration. If the right eye turns to the right, the left turns that way also. This is not a reflex action on the part of the left eye. It is an associated, or coördinate, movement. So, too, when a pupil contracts simultaneously with accommodation or convergence, or with both of these processes, that means only that the pupil contraction, the accommodation, and the convergence are three coördinated functions looking to one common end, *i. e.* seeing close. If we want to see close and to do this properly, we must first perform these three simultaneous acts — accommodate our lenses, converge our visual lines, and contract our pupils. Not one of these functions is a reflex result of any of the others. The others are simply executed at the same time and for the same purpose.

Out of this associated trio of actions, we can, artificially, strike out either the accommodation or the convergence, and yet keep the other two actions. We cannot, however, strike out the pupillary contraction alone, and keep convergence and accommodation: there is no way known to do so, or at least to do so accurately.

We can strike the accommodation out by placing in front of the eyes +4.00 D lenses. Then if the eyes look close, convergence occurs and pupillary contraction, but the +4.00 D lenses prevent accommodation. We can, again, strike out the convergence by placing before the eyes prisms of a strength proper to substitute the meter-angles and with their bases in. Then, if the eyes look close, accommodation

occurs and pupillary contraction, but not convergence. The prisms keep the visual axes parallel.

Almost all these facts have, from time to time, the most practical consequences. The truth of this statement will be apparent to you if you will only be so kind as to consider this paper more fully at your greater leisure.

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Limit of Visibility in the Ultra-violet*

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THE following is in the nature of a memorandum of some experimental work undertaken in the Research Department of the American Optical Company in 1919-1920 on the question: "Where does the ultra-violet begin?" The obvious answer is that there can be no definite wave-length marking the transition from the visible to the invisible. But we can set a somewhat arbitrary practical boundary. It is not the purpose of this article to set such a limit, but merely to collect the results of preliminary unpublished observations.

The experiments were confined to what could be done with the apparatus available and while a good deal of time was consumed in combination and re-combination of different parts of the apparatus, it is only worth while here to collect the results of two set-ups, the light source being the same in both cases. The observations were made almost entirely by one person.

We shall define visibility, for our purpose, to be the perception of a retinal image of a real spectrum line free from instrumental fluorescence. This does not exclude the possibility that all vision in the ultra-violet is due to fluorescence of the retina acting like automobile oil on a photographic plate. Automobile oil fluoresces to the ultra-violet and increases very markedly the intensities of the ultra-violet lines. In all that follows especial attention has been paid to the avoidance of misjudgments by using quartz optical parts, by the consideration of ghosts, by attempts to use the apparatus at its maximum efficiency, by the use of a Crookes glass screen and by verification of wave-lengths.

* It will be of interest to read this article in conjunction with the paper on *The Absorption of the Eye for Ultra-violet Radiation*, by Miss Graham, in this issue of the *Journal*. The conclusions of the two papers have been reached by entirely different experimental methods.

Light Source

The ordinary light circuit was used to get a high-tension spark. The 110 volt A. C. power line with about 10 ohms resistance passed to a ½ K. W. 15,000 volt transformer and a 0.007 microfarad condenser, producing a high frequency spark discharge. Sufficient self-inductance was added to the circuit and taken out at will to change the character of the spectrum.

Plane Grating Spectroscope

A replica of a Rowland grating (15,000 lines to the inch) was set on the Stanley and Bellingham spectrometer in the room adjoining the room containing the spark. The objectives have a clear aperture of 20 mm. and focal length 245 mm. The glass objectives belonging to the instrument were replaced by quartz. In place of the usual glass eye-piece a small quartz lens of about 57 mm. focus was used. The grating replica was made of histoloid and mounted on quartz. A deep purple screen of Corning glass G55 - A62 was sometimes used to advantage before the eye. A screen of Crookes glass served as an excellent criterion for spurious lines. Any real ultra-violet line below 360 $m\mu$ is cut off by the interposition of this screen.

Concave Grating Spectroscope

This instrument was made in the laboratory by Mr. Tillyer, using an Anderson concave grating on speculum metal, radius of curvature being ½ meter, ruled 20,000 lines to the inch. It is mounted as shown in the diagram below. In this case the light source and the spectroscope were in the same room and no attempt was made to push the limit to the extreme ultra-violet. Owing to the intense light of the spark the eye could not be said to be dark adapted. No screens were interposed. This instrument gives a four inch spectrum of excellent definition.

Experience with the spectrum of iron led to the use of other metals having fewer lines so as to reduce the total spectral illumination, but possessing some strong ultra-violet lines between 400 and 300 mμ.

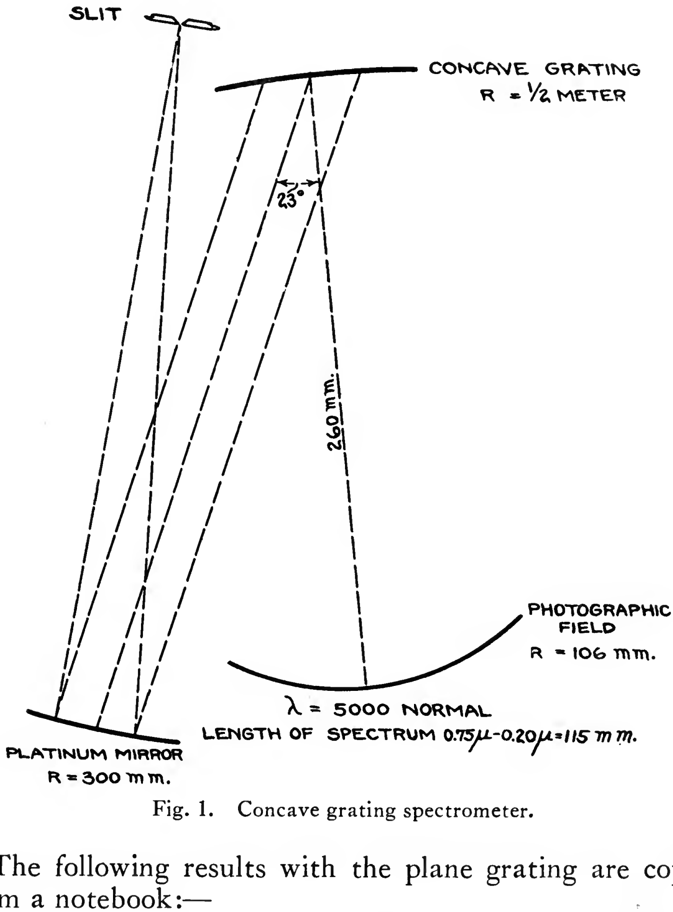


Fig. 1. Concave grating spectrometer.

The following results with the plane grating are copied from a notebook:—

Cadmium. Best results for electrodes close. Not much difference, with or without inductance. Approximate set-

tings for angular deviation of ray gave sufficiently good wave-lengths for identification of 325, 340, 346, 361 mμ.

Bismuth. Melting point too low.

Zinc. Best results without inductance, little resistance and electrodes close. Saw 328, 330, 334 mμ with difficulty by oblique vision.

Tin. Saw 333 (blend of two), 327 (blend of two) and 317 mμ. Better with inductance. Last line 317 mμ very easy.

Silver. Saw 328 and 338 mμ very well. Mr. T. could not see them; Mr. B., Dr. S. and Mr. K. all saw them readily. These two silver lines are excellent for this region.

Aluminum. Saw pair at 394, 396 mμ *very* strong and pair at 358 and 361 mμ not so readily.

Iron. Thin electrodes and thick ones. Saw down to about 363 mμ. Thin electrodes became incandescent and gave out continuous spectrum. Line spectrum less bright than arc.

Conclusions. Spark intensities hard to control. Visibility depends upon a good many factors. Greenish glow troublesome at times, more so without inductance. Last line seen is 317.5 mμ.

The results with the concave grating are summarized in the table entitled "Spark Spectra" on the opposite page.

With three exceptions the last line visible when there is no self-inductance is the air line 399.5 mμ. With self-inductance the limit is conditioned by the last strong line in the same neighborhood. The apparatus photographs the ultra-violet to 200 mμ.

One modification of the first set-up is worth recording. The spectrum of an iron arc was thrown on the hole in the wall and only the blue and violet were passed through to the spectroscope in the next room. Having eliminated most of the intense light of the visual region, the field glow was less troublesome. The limiting wave-length observed was 320 mμ and was seen with difficulty. This

SPARK SPECTRA

Element	Capacity Only	Capacity and Inductance
Fe	400.5	404.6 Fe
Bi	399.5 Air	Melted
Au	399.5 "	405.5 Au
Pb	399.5 "	400.5 Pb
Al	394.4 Al	394.4 Al
Zn	399.5 Air	410 band?
Cd	399.5 "	405.8 Cd.
Ag	399.5 "	405.5 Ag
Cu	399.5 "	402.3 Cu
Sn	399.5 "	405.5 ?
Pt	399.5 "	400 Air band?
Wo	399.5 "	393.4 Ca
Graphite	392 C	385 Cyanogen
Ordinary cored carbon	399.5 Air	385 "

result is interesting because the apparatus could not be expected to reach farther. The grating replica was mounted on glass. A single eye lens was of glass, making a thickness of about 4 mm. The transmission of crown glass is given by the Bureau of Standards for a smaller thickness.

TRANSMISSION OF CROWN GLASS 1.68 mm.

Wave-length (mμ)	Per Cent
320	55
310	34
300	12

Moreover, the exit pupil of this instrument was smaller than the pupil of the observer's eye when dark adapted. The difficulty encountered with this set-up consists in holding the region of maximum intensity on the very narrow and faint ultra-violet lines under observation.

If an absorbing screen could be placed at the slit it would not be necessary to make the first dispersion. Solutions of copper sulphate and ammonia were tried unsuccessfully. When opaque enough to cut out the intense visual region the cell also cuts out the very weak ultra-violet.

A carbon arc, the positive pole of which contained a bismuth core, was observed visually and also photographed. Lines at 360, 351, 340 and 328 mμ were seen. In the spectrogram the Bi line at 307 mμ was very strong, yet was not seen at all. Similarly the spectrograms of cored carbons registered the cyanogen band at 388.4 mμ brighter than the Ca lines 393 and 397 mμ; visually the cyanogen band was much weaker. Lines below 400 mμ, when seen at all, are much fainter than the spectrogram indicates. Barring a considerable rise in emulsion sensitivity for this region, the conclusion is drawn that for my eye there is a rather sharp, deep loss of sensitivity just below 400 mμ.

With the plane grating set-up the limit of visibility is near the limit of the apparatus and the observer's eye. Any one of three things may be the limiting factor: intensity of the radiation, transmission of the apparatus, sensitivity of the observer's eye. These observations are best summarized by saying that my own eye can see readily the Sn line at 317.5 mμ provided the source of light is so intense that it overbalances a physiological insensitiveness.

In the case of the concave grating the instrument limits the spectral intensity of the ultra-violet and this set-up is better adapted to the determination of a limit under ordinary conditions of observation. So far as these observations go, they point to the suggestion that the round number 400 mμ is a good practical dividing line between the visual spectrum and the ultra-violet.

Physiological experiments on the transmissive powers of the media of the eye indicate that the region 317 mμ should not be visible. On the other hand Helmholtz[1] records the observation of the entire ultra-violet spectrum

of the sun, using two dispersions and having all optical parts of quartz. This latter precaution was not always maintained by the older observers, hence some of their results must be discarded. Not only did the light pass through crown glass, but even flint. An achromatic objective would transmit nothing lower than 350 $m\mu$ probably and a flint prism nothing lower than 380 $m\mu$, depending upon the particular piece of flint.

[1] Helmholtz: *Handbuch der Physiologischen Optik*, Zweiter Band, Seite 93.

Research Laboratories
American Optical Company

The Absorption of the Eye for Ultra-violet Radiation*

Winifred P. Graham, M. A.

THE eye, as the most delicate sense organ, has always been of great interest, and any investigation adding anything to the sum total of knowledge concerning it, would seem to be worth while. Several investigations have been carried on to determine the relative sensibility of the eye for light of different wave-lengths, but data concerning the limits of the visible spectrum, and the absorption of the tissues of the eye, is conflicting and lacking in information regarding the source and condition of the material. It is, of course, a well-known fact that the eye is sensitive to only a very small portion of the total radiation. The question naturally arises as to whether the limits of our vision are determined by the wave-lengths. Nutting says[1] that the retina is most sensitive to radiation in the blue-green between wave-lengths .50 and .55μ; that good seeing requires radiation between wave-lengths .41 and .75μ; and if the source is sufficiently intense radiation as far out as wave-length .321 (ultra-violet) or 1.0μ (infra-red) may be perceived. F. W. Edridge-Green states[2] that the limits of the visible spectrum are practically the lines *A* and *H*, *A* wave-length .764μ for the red and *H* .3968μ for the violet. He also states that the wave-lengths vary with different persons. It may be seen that there is quite a discrepancy between these two writers.

The production of fluorescence in the eye is an important consideration. Wrong conclusions are likely to be drawn as

*The Editor of the *American Journal of Physiological Optics* is pleased to acknowledge his indebtedness to the author and to the editor of the *Journal of the Optical Society of America* for permission to use this article.

It will be of interest to read this article in conjunction with the paper on *Limit of Visibility in the Ultra-violet*, by Miss Glancy, in this issue of the *Journal*. The conclusions of the two papers have been reached by entirely different experimental methods.

to the limits of the visible spectrum from such experiments as those of Helmholtz and others. When a portion of the spectrum is exposed and produces merely the sensation of light, there is no definite proof that the short wave-lengths actually reach the retina, as they might be transformed into long wave-lengths by the tissues of the eye. This would be equivalent to a source very close to the retina. On the other hand, if a slit were used with some characteristic shape such as an arrow, for example, if a distinct image were formed with the slit illuminated with ultra-violet, it would seem to prove that we can see by means of ultra-violet light. Nutting's observation is borne out by a member of the Physics Department of this University who claims to have seen the doublet of the mercury spectrum (.3132μ and .3126μ). It might be possible that about the same wave-lengths get through the average eye but that the sensitiveness to the ones near the absorption band varies with the individual.

Dr. Fritz Schanz studied[3] the effect of the ultra-violet light on the eye and the absorption of the different parts. He used a quartz spectral photometer and a Nernst lamp. The corneas of three people of different ages were investigated. He found that the cornea begins to absorb at .360μ, and at .310μ the rays of the Nernst lamp were absorbed completely. He studied the lenses of three different people of ages 40 and 28 years, and a child's. He states that the lenses begin to absorb in the blue and absorb extensively in the ultra-violet. Using a quartz spectograph he took photographs of the absorption of the cornea and the lens. The latter was pressed between two quartz plates to a thickness of 3 mm. Since the lens in the region of the pupil is considerably thicker than 3 mm., this would only give the partial absorption. His plates show that the cornea begins to absorb at .360μ and absorbs completely at .300μ and the lens absorbs completely at about .350μ on a forty-second exposure. This exposure varied from twenty to forty seconds.

In a second article[4] in 1920, he apparently refutes the data given in the former discussion. This time he used a quartz spectograph. He states that nearly all the ultra-violet is absorbed but, although that which is left reaches the retina, it does not produce the sensation of light but of fluorescence. By using an intense source he says it is possible to perceive light up to .392μ, and if there is light beyond this it is caused by the fluorescence of the retina.

Dr. W. E. Burge gives[5] an absorption spectrum of the cornea of a rabbit which transmits wave-lengths as short as .297μ.

The object of this experiment was to determine what wave-lengths in the ultra-violet region get through the tissues and liquids of the eye, or in other words, what light, in the ultra-violet region, actually reaches the retina. It was also determined to compare the absorption of the various parts of the eye and to point out, as much as the material which could be procured would permit, the change in the absorption due to disease, solution in formaldehyde, etc.

The measurements are not as numerous as was wished on account of the difficulty of obtaining material. Human eyes were desired immediately after death and before embalming, or soon after removal in the case of enucleation operations. The specimens procured by the latter method can usually only be used in part because of some pathological condition.

Apparatus and Materials

A quartz-prism spectroscope was used, with a dispersion of about 4 inches. A cadmium spark furnished the source of radiation. A transformer connected with nine storage cells gave a good spark across a gap of about a centimeter. The electrodes were sticks of cadmium formed by drawing the molten metal up into small glass tubes. These were stuck through a hollow cork and connected to some Leyden jars and thence to the transformer.

A holder was made for the corneas examined out of thin copper sheeting. Two pieces were cut approximately two inches square and an oblong hole cut in each ½ cm. x 1½ cm. A fold of a half centimeter was then made along the edge of one and the other trimmed off an equal amount. Thus one slipped into the fold and the holes coincided. The cornea to be examined was cut off where it joined the sclerotic coat and placed between the two plates, covering the openings. The edges opposite the fold were then placed in a clamp.

Since the crystalline lens in a fresh condition is fairly soft, stiff paper was found very satisfactory as a holder. A cardboard screen was used about 8 by 10 inches with a circular hole of an inch diameter cut in it. The screen was

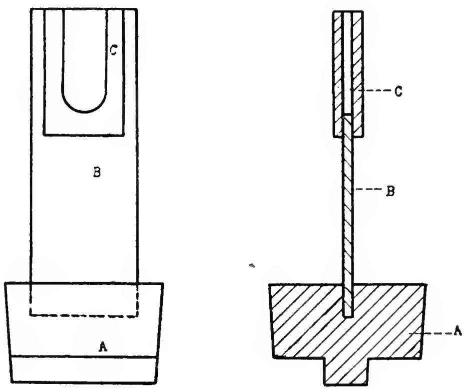


Fig. 1. Diagrammatic sketch of examination cell.

then covered with black paper on each side. A round hole, slightly smaller than the lens to be examined was cut in either side of the black paper, concentric with the hole in the cardboard. This served as a very convenient socket for the lens.

The liquids of the eyes were put in a small quartz cell

for examination. An oblong cut with a semicircular bottom was made in one end of a cover glass, see Fig. 1. Quartz plates of 2½ mm. thickness were fastened on either side of this with sealing wax. A small container was thus formed with 1½ mm. thickness, 1 cm. width, 2½ cm. depth. This was very satisfactory as four or five drops could be examined.

The animal eyes used (specimen numbers 1-6) were those of cows, pigs, and sheep. These were mostly secured while they were yet warm, dissected and used the same day. Some were put on ice and dissected and used some four or five days later.

Specimen No. 7 of the human material was secured from an enucleation operation. It was the eye of a man aged twenty years who had been struck in the eye two years previously with a pen point. The puncture seemed to be completely healed as there was no mark on the cornea, which appeared to be normal. The aqueous humor also seemed normal. On dissecting the eye the lens was found to be completely calcified. The choroid had been nearly all absorbed and in its place was a layer of salt. The vitreous humor was very thin and resembled bloody water.

Specimen No. 8 was the lens taken out in a cataract operation. The cataract was mature.

Specimen No. 9 was a lens obtained from a cataract operation. This cataract was not so fully developed. Both these lenses were intact when received and both of the patients had the perception of light and darkness. The lenses appeared opaque in the center but seemed to transmit quite a good deal of light around the edges.

Specimen No. 10 was the lens of an infant of 4 months. The eye had been infected at birth. The lens only was used and it appeared perfectly normal. This view was corroborated by the physician and ophthalmologist in charge.

Procedure

The method used in determining the amount of absorption was one of comparison. Plates were taken of the sparks of

cadmium, zinc and tin. The wave-lengths on these were marked, see Fig. 2, by comparison with the photographs and data given by Eder and Valenta[6]. Cadmium was found to be most satisfactory for this purpose, as has been mentioned before, because the groupings of the lines are very characteristic and the spark can be easily maintained for a comparatively long time. Spectral photographs were then taken with the material in front of the slit and compared with the original photograph. In some cases the material only covered part of the slit so that a comparison spectra was given on the same plate.

The plates were examined with a small lens and the last line toward the ultra-violet end of the spectrum was taken as the last wave-length to be transmitted, or the beginning of the absorption band.

A cut was made in the edge of the cornea and the aqueous humor was removed. The cornea was then cut off and the lens taken out. Then the posterior of the eye was cut into and a small amount of the clear vitreous removed.

The cornea was put in the holder mentioned above and placed before the slit of the spectroscope. Exposures of varying time were made in order to determine the amount of absorption.

The lens was placed in the cardboard screen and the light from the spark focused by means of it on the slit.

The humors were placed in the quartz cell and put directly in front of the slit and very close to it.

Date and Results

The data obtained are given in Tables I to IV.

Seed dry plates number 26 were used except for spectrograms 15 and 16 for which Seed Process plates were employed. The lines were often very faint and at times it was hard to tell just exactly where the last line was located. The last wave-length toward the ultra-violet as given in the last column of the data is only a close approximation

TABLE I

Cornea

No. of Specimen	Kind	No. of Plate	Time of Exposure	Condition of Specimen	Last Wave-length
1	Cow	13	1 1/2 min.	In formalin	3251
1	"	14	3 "	" "	3251
2	"	20	1 "	Fresh	3134
5	Pig	29	1 "	4 days on ice	3251
7	Human	36	30 seconds	Fresh	3066
7	"	37	45 "	"	2981
7	"	38	60 "	"	3066
7	"	39	1 1/2 min.	"	2981
7	"	40	2 "	"	2981
7	"	41	25 "	"	2981

TABLE II

Crystalline Lens

No. of Specimen	Kind	No. of Plate	Time of Exposure	Condition of Specimen	Last Wave-length
1	Cow	15	3 min.	In formalin	3613
1	"	16	3 min.	" "	3613
2	"	19	15 sec.	Fresh	3251
2	"	18	30 sec.	"	3251
3	Sheep	21	45 sec.	Kept 3 hours	3251 (very faint)
3	"	22	60 sec.	Fresh	3134
3	"	23	18 min.	"	3134
3	"	24	45 min.	"	3134
10	Human infant	50	1 min.	Fresh	3134
10	"	49	20 min.	"	3134
8	Human	44	25 "	"	4415
9	"	45	25 "	"	3404
6	Pig	33	45 sec.	5 days on ice	3251 Not very definite
6	"	34	45 sec.	"	3134
6	"	35	20 min.	"	3134

since when partial absorption has set in only the strong lines of the source show. Also it might be possible for the transmission to continue for several wave-lengths further and not show on the plate if there was no line in the cadmium spectrum where the absorption began.

Table III

Aqueous Humor

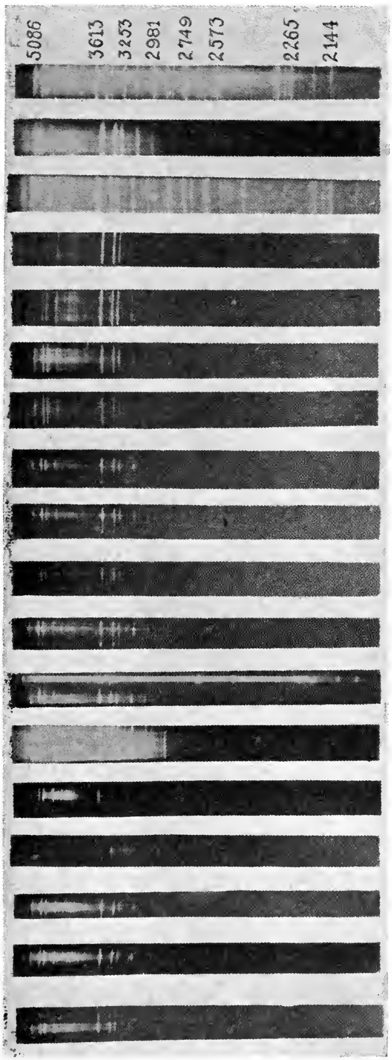
No. of Specimen	Kind	No. of Plate	Time of Exposure	Condition of Specimen	Last Wave-length
4	Sheep	27	15 sec.	Fresh Kept 3 hours	2145 (very faint) 2145
4	"	26	30 "	"	2145
4	"	25	45 "	"	2145
4	"	28	60 "	"	2573
7	Human	42	20 "		2573
7	"	43	40 "		

Table IV

Vitreous Humor

No. of Specimen	Kind	No. of Plate	Time of Exposure	Condition of Specimen	Last Wave-length
5	Pig	31	15 sec.	4 days on ice	2265
5	"	30	30 sec.	"	2313
5	"	32	1 min.	"	2265

It can be seen from the data that most of the absorption bands begin rather abruptly; that is, the region of partial absorption is not very great, as long exposures did not bring out many additional lines.



1. Cadmium.
2. Cd. Cover glass.
3. Cd. Water.

13. Cd. Cornea (cow) 1.5 min. in formalin.

14. Cd. Cornea (cow) 3 min. in formalin.

20. Cd. Cornea (cow) 1 min. Fresh.

29. Cd. Cornea (pig) 1 min. 4 days on ice.

36. Cd. Cornea (human) 30 sec. Fresh.

37. Cd. Cornea (human) 45 sec. Fresh.

38. Cd. Cornea (human) 60 sec. Fresh.

39. Cd. Cornea (human) 1.5 min. Fresh.

40. Cd. Cornea (human) 2 min. Fresh.

41. Cd. Cornea (human) 25 min. Fresh.

15. Cd. Lens (cow) 3 min. in formalin.

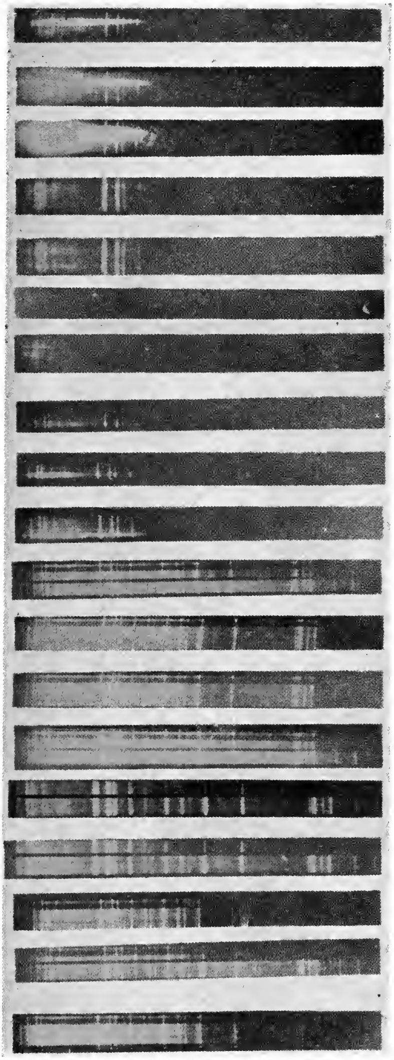
16. Cd. Lens (cow) 3 min. in formalin.

19. Cd. Lens (cow) 15 sec. Fresh.

18. Cd. Lens (cow) 30 sec. Fresh.

21. Cd. Lens (sheep) 45 sec. Kept 3 hours.

Fig. 2. Spectrograms of absorptions by cornea and lens of eyes.



22. Cd. Lens (sheep) 1 min. Fresh.

23. Cd. Lens (sheep) 18 min. Fresh.

24. Cd. Lens (sheep) 45 min. Fresh.

50. Cd. Lens (human infant) 1 min. Fresh.

49. Cd. Lens (human infant) 20 min. Fresh.

44. Cd. Lens (human) 25 min.

45. Cd. Lens (human) 25 min.

33. Cd. Lens (pig) 45 sec. Kept 5 days on ice.

34. Cd. Lens (pig) 45 sec. Kept 5 days on ice.

35. Cd. Lens (pig) 20 min. Kept 5 days on ice.

27. Cd. Aqueous Humor (sheep) 15 sec.

26. Cd. Aqueous Humor (sheep) 30 sec.

25. Cd. Aqueous Humor (sheep) 45 sec.

28. Cd. Aqueous Humor (sheep) 1 min.

42. Cd. Aqueous Humor (human) 20 sec. Fresh.

43. Cd. Aqueous Humor (human) 40 sec. Fresh.

31. Cd. Vitreous Humor (pig) 15 sec. Kept 4 days on ice.

30. Cd. Vitreous Humor (pig) 30 sec. Kept 4 days on ice.

32. Cd. Vitreous Humor (pig) 1 min. Kept 4 days on ice.

Fig. 3. Spectrograms of absorptions by lens, aqueous humor and vitreous humor of eyes.

Although the aqueous humor of specimen 7 seemed to be normal, it is apparent from Table III that it was not. It seems very probable to suppose that it had absorbed additional salt as well as the posterior part of the eye and the lens. The cornea of specimen 7 (Table I) seems to have been normal, or at least nearly so.

Conclusions

The following conclusions may be drawn from the foregoing data:

1 The combined tissues of the eye absorb the ultra-violet radiations up to the neighborhood of .3134μ.

2 The lens has the largest region of absorption.

3 Formalin changes the absorption.

4 Any injury or disease tending to increase the salt content in the eye radically changes the absorption.

Further, it might seem reasonable to suppose, although the data here given are scarcely definite enough to say conclusively, that the absorption in the animal's eyes does not differ radically from that in the human.

In conclusion, I wish to thank Dr. R. S. Minor for his help; Drs. L. D. and A. S. Green for kindly supplying me with the material; and all others who made this work possible.

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A New and Sensitive Astigmatic Test Dial*

Charles Sheard, Ph. D.

FOR some little time the writer has been carrying on some investigations on the general subject of improvements in visual acuity and subjective astigmatic tests. In this paper he is desirous of disclosing what he believes to be a new and extremely sensitive subjective test for astigmatism. Its sensitivity easily detects an eighth diopter of astigmatism and with an astigmatic error of a quarter of a diopter the axis of astigmatism can be located to within two or three degrees quite readily.

With the best forms of subjective test charts, such as the better made forms of radiating line charts, many persons under examination have some difficulty in determining which line is most distinct (or most indistinct) and in what position.

The test object to which the writer calls attention consists of an opaque disc, painted a dead black on the side facing the subject under examination, and bearing a series of square apertures along two diameters exactly at right angles the one to the other (Fig. 1). These square apertures and the distances between them each subtend an angle of one minute to a minute and a half for the customary distances of fifteen to twenty foot testing. The disc, which should be made of a rigid plate of metal and at least a foot in diameter, rotates about a central horizontal axis so that either diameter of apertures may be placed at any required

*Since this article was written, the writer has had the pleasure of reading a paper by E. Le Roy Ryer on The Essentials of a Practical Test Chart, *Archives of Optometry*, January, 1923, pp. 20-29. On pages 25 and 26 we find a description, in brief form, of the Ryer astigmometer. The following comments are made:—"This consists of *two series* of *parallel lines* and revolvable 180 degrees." (The writer of the present article recommends two *single* diameters of squares at right angles to each other, believing that this affords less confusion to the person under test). "If no astigmia exists the lines or squares remain symmetrical throughout, but if the smallest amount of astigmia exists, rotation causes the lines to break and every square, both colored and open, to assume the form of a rhomboid giving a very marked cane-seat effect."

position, which position is determined from a fixed graduated scale attached to the front face of the box containing the sources of illumination. The illumination of the perforated diameters should be uniform and well diffused. The diffusion is best accomplished by means of simple diffusing media covering the lines of apertures.

If a condition of astigmatism exists, therefore, as the disc is slowly turned one line of apertures will be seen as a continuous line (Fig. 2), while the diameter at right angles will appear to consist of a series of apertures elongated at right angles to this line. The phenomenon present is, therefore, one of a continuous line and narrow rectangles in a line at right angles to each other. When the lines of apertures are in any other positions than the principal astigmatic meridians of the eye under examination, the two diameters will appear to consist of a series of tilted or skewed apertures (Fig. 3).

In practice such a test may well be used somewhat as follows: Under the fogging method and using the radiating line chart with lines separated by ten degrees, the approximate axes of astigmatism may be located. The rotating disc with perforated diameters is to be then employed and set such that a series of rectangular aperture is seen in one meridian as the fog is reduced and the other line of apertures is seen as more or less of a continuous line. If a series of distorted apertures occurs the dial is to be rotated until this disappears. The test of the amount of astigmatism consists in the finding of the cylindrical lens that will give equality of appearance to the two lines of illuminated apertures.

If the sizes of the alternate square apertures and opaque portions of the two diameters at right angles are based upon the one minute angle for the distance at which they are to be used, then the fogging lenses used will need to be reduced until the perforations in one meridian are seen quite distinctly as squares or rectangles. In that case, therefore,

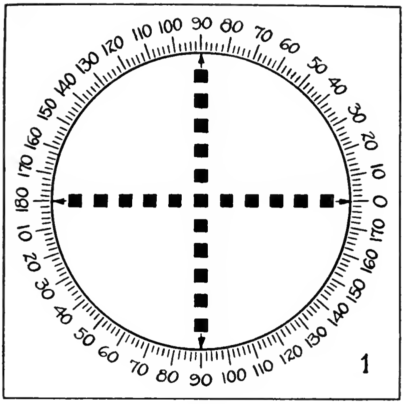

Fig. 1. Astigmatic test-chart with series of square apertures in two diameters.

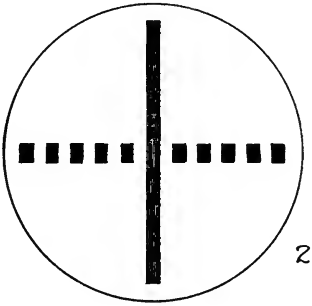

Fig. 2. Appearance of apertures in a condition of astigmatism, when correct meridians are found.

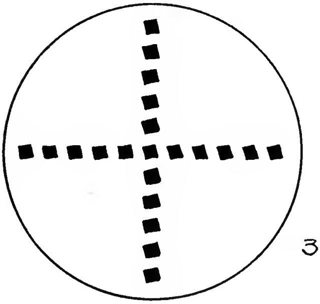

Fig. 3. Appearance of apertures when principal axes of astigmatism have not been exactly—but quite closely—determined and amount of astigmatism practically obtained.

one astigmatic line of the interval of Sturm will be at or very close to the retina and the other line will always be in front of the retina. If, then, the squares are not slanted or do not appear to be slightly twisted, we are certain that the two principal meridians have been determined, and we proceed to bring the refractions of the two meridians to equality through the use of that minus cylindrical lens which, when placed with its axis parallel to the line of most distinct apertures—or least continuous line appearance—produces similarity of apertures in both meridians.

The form of this test may also be varied in that, instead of using perforated diameters with diffused illumination from the rear, a chart may be employed in which alternate white and black squares, subtending the proper angle, are printed upon it and illuminated from the front side. Furthermore, the writer would call attention to the fact that such a chart, when properly constructed by either method, may be used to determine the astigmatic conditions at the reading point or customary close-working distance of the person under test.

Division of Ocular and Professional Interests,
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Editorials

The Editor and the Publishers of the *American Journal of Physiological Optics* do not hold themselves responsible for the opinions expressed by the various contributors. From time to time there are articles, appearing in this *Journal*, with which the Editor and doubtless many readers cannot agree, either in whole or in part, as to the methods pursued or the conclusions reached. Such articles are printed in the hope that they will stimulate further investigation and research. The great discoveries in the scientific world have been made by men and women who have had the courage to depart from the "beaten path." "Herd thinking" is rarely conducive to a creative thinking." This is the spirit in which the articles in each and every issue of this *Journal* are presented to the readers.

Some Fundamental Points in Testing and Correcting Astigmatism

QUITE recently we read an article or book and excerpted and placed in a notebook, which we keep for that purpose, a sentence to which we can heartily subscribe because it contains very simple but fundamental advice of everyday value to the refractionist. But we failed, in the interest we took in transcribing the words of another, to note the name of the author or the work from which it was taken, so we cannot give the credit to the one who put on record an old and, by many, long accepted rule: "As much plus or as little minus spherical power as the patient will accept, combined with the *weakest minus cylinder*, simplifies the work of refraction and insures accuracy without waste of time." But the great point at issue is the determination of the proper amount of minus cylinder and the location of its axis.

In the first place, therefore, the writer has long since discarded the use of plus cylinders in either retinoscopic or subjective tests. In skiametric determinations, the procedure is to first correct with spherical lenses the maximum

hyperopic or minimum myopic meridian and to then determine the amount of astigmatism through the use of minus cylinders. While this second portion of the static skiametric examination is being carried out, an occasional observation is made with reference to the accuracy of correction of the first meridian, for quite frequently additional convex lens power can be added in cases where a cycloplegic is not employed. The procedure in carrying out the subjective tests is fundamentally identical.

In every instance in which astigmatism exists there is present what is commonly known as the conoid of Sturm, or the interval of Sturm. The characteristics of this conoid may be easily demonstrated through the employment of any convex sphero-cylindrical lens combination, such for example as a +4 D.S. $\supset$ +3 cyl. ax. 90, using a beam of light from a distant source, say twenty or more feet, and a suitable receiving screen. The beam of light passing through the combination will be thrown on a screen held behind the lens as a luminous patch of light. The size and shape of this patch of light will change with a shifting of the position of the screen. If the screen is placed 14.3 cm. back of the lenses, a vertical line of light will be formed. This is known as the anterior focal line and is produced by the meridian of greatest power. As the screen is moved back, this vertical line will change into a probate oval, then into a circle, called the *circle of least confusion*, which passes into an oblate oval, and finally into a horizontal line of light, or the posterior focal line. Using the data assumed, this line will be found at a distance of 25 cm. behind the lens, or at a position remote from the sphero-cylindrical combination equal to the focal length of the sphere only. The distance between the anterior and posterior focal lines is known as the *interval of Sturm*. The anterior focal line is shorter and somewhat more distinct than the posterior focal line.

Such simple experiments as these give us some notions of the nature of astigmatic refraction, although the re-

searches of Gullstrand have shown that the diffusion images existent in an eye which requires a sphero-cylindrical correction are not the regular lines and ovals obtained with a sphero-cylindrical lens combination as described in the foregoing paragraph. Rather are they more like stellate figures. The manner in which the light is concentrated in the diffusion images determines the sharpness or clearness of vision, rather than the size and shape of these images. If, for example, the greater part of the light is concentrated in the center of one of these images, the rather indistinct, hazy surrounding area will not be appreciated and the image will be designated as clear. And so, while no eye is probably ever so constructed as to refract a pencil of light rays in conformity with the classical investigations of Sturm, *i. e.*, the conoid, yet only in so far as the refraction of the eye takes place in conformity with this conoid can we correct astigmatic errors with sphero-cylinders or cylinders.

This, therefore, gives us the basis of our ordinary subjective tests with charts of radiating lines or fan-charts. The writer has discarded the common form of astigmatic dial known as the fan-chart with its sets of two or three lines lying at zero, thirty, sixty, ninety—and so on—degrees, for the obvious reason that the axis of astigmatism may lie intermediately, and thirty degrees is too wide an interval. He much prefers a chart of the type devised by Lancaster, with single radiating lines, each line being ten degrees from its neighbor, the whole circle being thus divided up. In various places we have found records indicating that a substantial background of extreme *whiteness*, such as can be obtained with so-called wedding cardboard, together with strips of black velvet baby ribbon, form an excellent astigmatic chart. Extreme whiteness and blackness of the contrasting elements are desirable. Some recommend that the black strips of ribbon be glued to the cardboard but the writer believes it is better to use a little more ribbon, make proper perforations in the cardboard and to lace the ribbon.

This may be easily done, since the radiating lines should not meet at a common center but should terminate in the circumference of a central circle having a radius of fifteen to twenty centimeters.

The Verhoeff charts are excellent, but we do not believe that they are superior to, if actually equal to, the Lancaster chart as just described. Quite recently Maddox (*vide* under "Abstracts" in this issue of the *Journal*) has proposed a quite simple and apparently sensitive test for the location of the astigmatic meridian in the form of an instrument having a rotating arm which carries a small disc lying in the plane of the chart. This disc carries on its face a large V, made of two equally black limbs. Not only may the distinctness or haziness of radiating lines—similar to the Lancaster chart—be used as a test, but one of the principal axes of astigmatism may be located when the two limbs of the V are judged to be equally distinct. The radiating line at which the point of the rotatable V points, when the two limbs are equally distinct, locates the meridian of astigmatic error to be corrected.

In the use of the Lancaster or other chart the examiner should remember that, if accommodation is eliminated, the perception of a line—such as a strip of black ribbon—is good if the direction of that line corresponds to the direction of the focal line existent in the internal of Sturm which is either at the retina or nearest to it. Hence astigmatism may be tested subjectively by the use of radiating lines, for the clearest or most distinct line will locate the axis of astigmatism, while its amount can be measured by the use of minus cylinders which will bring sets of radiating lines, or cross lines at right angles to each other, to a condition of equality.

The axis of the correcting minus cylinder should be placed in a direction coincident with the least distinct or blurred lines or at right angles to the most distinct or clearest lines. This is obviously true for the reason that the clearest and

most indistinct lines correspond to the focal lines of the eye. These focal lines are at right angles to the power meridians of which they are the foci respectively. The clearest chart lines are parallel in direction, therefore, to the most ametropic power meridian of the eye, hence the power of the cylinder is needed in that direction. In turn, the least distinct lines of the chart are parallel to the nearest emmetropic power meridian of the eye, hence the axis of the correcting minus cylinder should be placed in a direction corresponding to, *i. e.*, parallel to, the least distinct or most blurred lines or at right angles to the most distinct or apparently clearest lines of the chart.

All such astigmatic test charts should be uniformly and properly illuminated. The lighting should be as nearly the equivalent of daylight as possible, and the lighting units used should be so distributed (within suitable containers, so as to screen them from direct observation) as to avoid inequalities of lighting such as are often found in refracting rooms, in which, for example, one side or half of the chart appears either darker or of a different tint of background. We do not, furthermore, believe that the testing-room should be very appreciably darkened, since changes in size of pupils have some influence in the disclosure of an astigmatic error, especially a low one, and for the further reason that pupils, which are larger than under commonly existing conditions of good vision, may introduce errors due to the peripheral refraction. At any rate, irrespective of possible lack of universal agreement to some of the notions expressed in this paragraph, we have to say that the use of a two- or three-foot length of card carrying Snellen letters with a fan-test chart as a sort of tacked-on appendage, illuminated by a single low candle-powered lamp, enclosed in some sort of a reflector, and placed somewhere near the top of the whole arrangement, is a thing of the past from the standpoint of accurate work: and yet hundreds of examiners are still sticking to it.

The writer uses a large Lancaster chart for the purpose of determining the axis of astigmatism. Should the circumstance arise that two or more sets of lines are quite distinct, with intervening lines indistinct, one is then aware of a condition of irregular astigmatism. The usual procedure is to then resort to the reading of letters on the distance test-types, making the first attempts with minus cylinders, the eye being properly fogged, in the positions indicated by the findings from the astigmatic chart.

Following the determination of the axis of astigmatism, it is well to make use of a second chart made up of a rotatable disc carrying two sets of lines—each set containing two or three parallel and equally spaced black lines—placed exactly at right angles to each other, one set of lines being placed parallel to the axis of astigmatism already determined. Minus cylinders are then placed before the eye, with axes at right angles to the most distinct lines, in increasing amounts until the two sets of lines at right angles to each other are apparently equally balanced or equally distinct. Occasionally two or three different cylinders will afford equality. Some writers recommend that the strongest one should be used, or in other words that the power of the cylinder should be increased until reversal of distinctness of groups of lines takes place and that the cylindrical lens immediately preceding the one that causes reversal is the measure of the astigmatism. The writer would, however, suggest caution in accepting this statement and would prefer to adhere more closely to a correction approximating the weakest cylinder which produces equality, especially if the eyes under examination have never worn cylindrical corrections. As a matter of practice, from our experiences in routine refractive examinations, we have arrived at the conclusion that it is far more satisfactory to the person examined, from the standpoint of *comfort*, if the astigmatic error is left *slightly undercorrected.* In particular is this true if the condition is one commonly known as astigmatism against the rule.

The cross-cylinder method, involving a somewhat different procedure than is here being discussed, is a valuable asset in checking up the correctness of cylindrical findings. Also, after the final correction has been determined upon, the writer quite often checks up his subjective findings by either one or both of two simple and quick methods. The first method consists in slowly fogging out the full radiating line chart and making inquiry as to whether or not all lines appear to be equally indistinct as the blur under the fog increases. A second method is to take a low-valued cylinder —say a quarter diopter—and to alternately and quickly place it, in two positions at right angles to each other respectively, before an eye viewing the astigmatic chart, determining whether or not one group of lines parallel to the originally determined axis of astigmatism is brought out more distinctly than the set at right angles and then, upon shifting the extra cylinder ninety degrees, whether or not the set of lines lying ninety degrees away from the previously determined most distinct set assumes the supremacy as far as distinctness is concerned.

And furthermore, in the subjective methods of correcting astigmatism, there is another important phenomenon which must be borne in mind, namely, the *circle of least confusion.* This phenomenon may be quite convincingly demonstrated with a camera and a cylindrical lens. If the camera is properly focussed and a cylinder is placed in front of the cornea and a photograph taken of the radiating line chart, one meridian will be left in focus and the meridian at right angles will be most completely out of focus. The effects produced will approximate the condition of affairs as seen by the human eye astigmatic to the amount of the cylinder placed before the camera provided the camera is stopped down to an aperture having a size comparable with the average sized pupil. With the camera thus set, the focussing screw may be manipulated until a position is found in which the radiating lines all look practically alike, irrespective

of the presence of the cylindrical lens (say, of half diopter power) in front of the camera. While the lines all look alike, none of them are sharp and clear. The explanation is that, after the re-focussing, the portion of the interval between the two principal focal lines which falls on the camera plate is the interfocal circle or circle of least confusion. No one line is therefore blurred more than another, for the focus is in every instance a circle and not a point. The greater the astigmatism, the longer will be the diameter of the interfocal circle. The significance and application of all this can be seen in testing for astigmatism. The eye may shift the focal interval forward or backward by accommodating or relaxing in turn. In cases of low astigmatism it is probable that the preference is for the circle of least confusion, hence it is possible that the retina of an eye may occupy such a position as to be at the interfocal circle and hence mask or hide a low amount of astigmatism. In cases of fairly high astigmatism it is probable that a focal line is preferred. The fogging for the correction of astigmatism should not be too great in extent. The ideal condition for the correction of astigmatism would be to have one principal meridian with its focus exactly at the retina and the other in front of the retina. Since in practice we cannot very well tell how much relaxable accommodation is present, it is safer to produce a myopia of about half a diopter for one principal meridian and a higher degree of myopia for the other. In other words, both focal lines should be in *front* of the retina. In an eye fundamentally hyperopic, the fogging lens should be about a half diopter stronger than the strongest plus sphere that gives best vision. When, then, the naked vision is 20/20, it can well be fogged to 20/30. In a generally myopic eye, the spherical lens needed is one that will allow one or two of the astigmatic lines on the Lancaster chart to be quite clearly visible. These same statements apply even though a cycloplegic, including a long continued use of atropin, is resorted to, because there

is usually some accommodative action possible. Hence the use of the strongest convex or weakest concave sphere combined with minus cylinders is to be recommended to those employing cycloplegics because it reduces to a minimum the small amount of accommodation which may persist.

If, therefore, in testing, the posterior focal line is permitted to become located back of the retina, conditions are then set up which are conducive to accommodative action, and the retina may be brought to the circle of least confusion and thus the astigmatism actually present be covered or concealed. The question may properly be asked: Is there any way of finding out whether the fogging is such that both focal lines—*i. e.* the whole focal interval—are in front of the retina? With proper fogging, a plus cylinder will make the lines parallel to its axis more blurred than they were previously, whereas a minus cylinder will make the lines parallel to its axis sharper or clearer. If the posterior focal line falls behind the retina, then a plus cylinder will make lines parallel to its axis sharper than they were previously and a minus cylinder will make the lines at right angles to its axis clearer.

The retinoscopic findings should, we believe, be of the greatest assistance in determining the initial amount of spherical lens to be used and should be the great guide in the carrying out of the subjective tests. In general, when the fogging has been reduced to 20/40 or at most to 20/30, the patient's attention should be directed to the Lancaster or similar chart* and the subject asked as to whether all lines look alike or whether some are more distinct than others. It is possible that they all look alike because they are alike in their images on the retina, or else the difference

*A most excellent chart is that known as the "Orthops" chart devised by Lionel Laurance, of London, England. This chart carries sets of two radiating lines at each of the 10 degree points of a semi-circle and also has a rotating card, bearing two sets of lines at right angles to each other, which can be set at any angle desired.

is not appreciated. If, however, with a quarter diopter cylinder the subject under test quickly and accurately detects a difference whichever way the cylinder is held and if no difference is seen when the cylinder is removed, then the examiner may conclude that the astigmatism amounts to less than a quarter diopter. When such a low amount of astigmatism is found to exist, the fog should be slight—from 20/30 to 20/24.

If, as the fogging is reduced, the horizontal (180°) line is picked, as the most distinct line and the vertical (90°) line as the least distinct or most blurred line, one would then proceed to add, let us say, a —0.25 cylinder, axis 90°. If conditions are improved but the vertical lines are still less distinct, —0.50 cylinder axis 90° would be used. If equality then exists, the astigmatic error may be considered as being properly corrected, unless one desires to choose between —0.37 and —0.50 cylinder. If the vertical lines should be blacker or more distinct than the horizontal ones, with a —0.50 cylinder, the astigmatic error would be overcorrected. In a case of no astigmatism, one will often find that with a —0.12 cylinder axis horizontal, the horizontal line becomes blacker and when the same cylinder is held axis vertical, that the vertical line becomes blacker or clearer.

Minus cylinders thus used in refractive examinations make the subjective testing quicker and augur for greater accuracy. With the strongest plus or weakest minus sphere and minus cylinders employed, changes in the cylinders only are required, whereas if plus cylinders are used, it is necessary to change both spheres and cylinders in the routine of an examination.

In concluding this article we may comment upon the fact that it may seem strange to many who read these paragraphs that, in this day and age, it is necessary to use printers' ink and paper to deal with one of the topics in visual optics presumably so well understood. Our only remark is to the

effect that there are scores of simple and fundamental things in this world about which many profess to be well acquainted but about which they are really quite lacking in information. And the subjective testing and correcting of astigmatism is one of these subjects in the category of physiologic optics as applied to the particular work of refraction.

Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

Samuel H. Robinson, O.D., F.O.S.

CHAPTER IV (*Continued*)

Oculo-Prism Treatment—General

Muscle and Duction Tests Before Treatment

A QUESTION refractionists have long desired to have answered is: "When shall I give muscle treatment?" In answer, it may be said that muscle treatment should always follow when these conditions, especially jointly, are more or less evident:—

1 When a muscle imbalance is indicated.

2 When, in addition, a low duction of one or more muscles is found qualifying the character of the imbalance.

3 When in addition to the above, eye-strain, in spite of proper refractive correction, is experienced.

The first two conditions, when of considerable degree, are sufficient to indicate, independently of the third, that muscle exercise is salutary if not imperative. These *two diagnostic steps*—mentioned in a former chapter—must first be taken before intelligent muscle treatment may be pursued. The proper manner to proceed, then, is to

1 Make the phoria or muscle tests, and

2 Make the duction tests.

These should be properly recorded as a means of reference, with which the subsequent muscular changes as affected by exercise may be compared.

Why Muscle and Duction Tests are Necessary

It may still seem vague to some as to why muscle and duction tests must precede every attempt at muscle exercise. This may be answered best by analogy. Supposing it were necessary for a man to lift 100 pounds with his right arm. How could it be determined whether or not he is capable of doing it? The most certain way to ascertain this is to give him a 100 pound weight and let him attempt to raise it with his right arm. Similarly, it is necessary that eye muscles, in order to perform duties with ease and comfort, shall have the ability to withstand a certain amount of prismatic power. How shall we know if such muscles possess the necessary power? Simply by subjecting these muscles to the proper degree of effort. When the limit of their endurance has been reached, diplopia will take place, and the prisms which have created it will register the maximum pulling power or duction of those muscles. Comparing the finding with the schedule for normal duction we have an accurate report on the status of those muscles. The muscle or phoria tests, on the other hand, by indicating the direction of the imbalance, *point out* the weaker muscles, aiding thereby in locating the muscles that are relatively deficient and in need of exercise. They are valuable, therefore, as a rapid and preliminary diagnosis of the trouble and suggest in advance a probable degree of the muscular insufficiency.

"Fusional Convergence Reserve," or Duction at the Reading Distance

While muscle tests are made both for near and far, duction tests heretofore have been made for distance only. As a result, no standard of muscular innervation at the reading distance is yet available. Should duction at the reading distance be interpreted as "maximum muscular innervation" entirely devoid of the accommodative-convergence function, then it must forever remain an indeterminable quantity. A logical and acceptable interpretation, however, may be

found under the title denominated by Sheard as "*fusional convergence reserve.*" *Near adduction and abduction*, as therein interpreted, represent only that innervation which is in excess of regular fusion or accommodative-convergence in force when fixing the reading distance.

Accordingly, the maximum amount of prismatic power, *apex in* (base out), about to create diplopia when fixing the reading distance, is a measure of "reserve *positive* fusion" (adduction at the reading distance), and the maximum prismatic power, *apex out* (base in), about to create diplopia at the reading distance, is a measure of "reserve *negative* fusion" (abduction at the reading distance), while both terms are embraced under the general heading, "fusional convergence reserve." This version of duction at the reading distance affords the only means by which muscular innervations at that distance may be estimated.

Keeping a Record of Findings

After determining the muscle and duction tests for the lateral and vertical muscles, a record of findings should always be made under the following heads:

MUSCLE TESTS	Esophoria	Distant Near
	Exophoria	Distant Near
	Right Hyperphoria	Distant Near
	Left Hyperphoria	Distant Near
	Cyclophoria	Distant Near
	Adduction	Distant Near*
	Abduction	Distant Near*
	Sursumduction	Distant Near*

Illustrating Significance of Muscle and Duction Tests

Assuming that a patient called for treatment, we shall analyze the significance of the following conditions presumably uncovered.

MUSCLE TESTS	Exophoria	Distant,	4 degrees
		Near,	12 degrees
	Right Hyperphoria	Distant,	1/2 degree
		Near,	1/2 degree
DUCTION TESTS	Adduction, 10 degrees		
	Abduction, 7 degrees		
	Sursumduction, 4 degrees		

The above muscle tests at once suggest that the trouble lies mainly in a weakened state of the internal recti muscles. The duction tests, which have followed, corroborate this finding and express definitely the status of these muscles. *In toto* we learn from these tests as follows:—

1 That the internal recti are the weak muscles; as expressed by 4 degrees exophoria.

2 That the right inferior rectus or the left superior rectus, or possibly both, are slightly weakened; as expressed by ½ degree right hyperphoria.

3 That the internal recti muscles lack proper innervation is further verified and their exact status indicated; as expressed by 10 degrees adduction.

4 That the external recti muscles may be accepted as practically normal; since abduction measures 7 degrees.

5 That the vertical muscles are but slightly deficient, which condition, if no strain or discomfort exists, may be considered negligible; since the right hyperphoria measures but ½ degree and sursumduction has reached as high as 4 degrees.

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* *Near adduction* is, in fact, the *positive convergence reserve; near abduction*, the *negative convergence reserve;* while *near sursumduction* expresses the extreme power of the vertical muscles at the reading distance with whatever influence fusion may exert upon them at that distance.

One can readily see what a comprehensive insight into the muscular condition is thus afforded by these preliminary tests. From the above data at hand, one would conclude that the major defect lies in the internal recti muscles which, when exercised to the point of muscular equilibrium and a state of normal adduction, should suffice to insure ocular comfort and proper nervous conservation. The next and final step, therefore, is to administer the necessary muscle exercise.

Giving Muscle Treatment or Exercise

Knowing that the major defect in a given case is, let us say, exophoria or a low state of adduction, we proceed to exercise the internal recti muscles so that the innervation may be increased to that degree which will establish normal adduction and a state of muscular equilibrium. Exercising a muscle consists in making it pull systematically and methodically. In ocular muscle work, to cause a muscle to pull, it is necessary that a prism be placed before its eye *with the apex over that muscle or in the direction of the desired pull.*

Accordingly, rotary prisms are set before the eyes as illustrated in Fig. 47 when making tests for adduction and abduction. The principle involved and method pursued are identical with those used in the lateral duction tests, with this difference. In making the test for *adduction*, for example, the internal muscles are compelled to pull *inwardly*, until their limit of endurance has been reached and diplopia becomes manifest. The degrees registered on the rotary prisms, as diplopia is about to take place, is the measure of adduction. The aim having been thus accomplished, work here ceases. In *exercising these muscles*, however, the same course is pursued but *consecutively* and *systematically repeated.* The prisms, *apices in*, are gradually increased in power until diplopia ensues. The operator makes a mental note of the adduction at that moment. Revolving the prisms back to zero, he starts over again. Once more he turns prismatic

power before the eyes until diplopia again occurs. Mentally he compares the present finding with the former reading. He thus determines at every step the innervational response to the exercise. After several exercises, the duction may show a slight increase, or possibly a momentary decrease. This latter condition generally signifies that the muscles under exercise have, as yet, but slight recuperative power, *i. e.*, are easily exhausted when subjected to strain, or, possibly, that the operator is prosecuting his treatment too vigorously. In such cases it is well to include suitable pauses between exercises.

It is the purpose, of course, with each exercise, from the moment prismatic power is placed in force until diplopia has been developed, that the muscles thus treated shall undergo a slow and gradual pull with an innervational stimulation in consequence. Just as when exercising the biceps with dumb-bells, every contraction and relaxation of those muscles creates a stimulus whose effect when made permanent contributes to a state of superior health and activity, so will the eye muscles when subjected to the influence of a constant but variable pull experience that improved innervation so essential in performing normal functions without strain or discomfort.

In giving exercise to the eye muscles we always set the prisms at zero, increasing them in power until diplopia develops, when the exercise automatically ceases. We then start again at zero, and repeat the same duction test. This is repeated over and over again with such pauses as circumstances warrant or a practical understanding dictates.

Giving muscle treatment, therefore, consists in continually repeating a given duction test, until the normal or desired innervation has been developed in the muscles thus exercised.

That the operator may be duly impressed with the method by which muscles are exercised, the following procedure should be carefully noted.

How to Build up a Weak Adduction

A *weak adduction* is almost invariably indicated by the imbalance *exophoria*.

With the patient's proper correction before his eyes, prisms are set in position as illustrated in Fig. 47. To build up the adduction, it is necessary that the *internal muscles* shall undergo a slow, steadily increasing pull. Beginning at zero, then, prisms must be rotated *slowly* so that the apices will turn *inwardly*. This means the *bases* must turn *outwardly*. As long as prisms have their bases instead of their *apices* marked, it will be necessary when rotating them to follow the *base* instead of the *apex*. Prisms are therefore rotated so that the *bases* turn in a direction *opposite* to that in which it is desired that the eye shall turn. One may then be assured that both the *apex*, and *eye* which follows it, are turning in the desired direction.

Thus, in seeking to build up the *adduction* by making the eyes turn *inwardly*, the prisms are rotated so that the *bases* will turn *outwardly*. Beginning, then, with *bases at zero*, one rotates the prisms so the *bases* turn *outwardly*, until the patient declares that two charts or two sets of letters are visible, when rotation must quickly cease and the total duction in degrees, registered upon both prisms, be noted. Again one starts at zero, and rotates the prisms, so the *bases* turn *outwardly* (which means the apices and eyes are turning inwardly) until diplopia develops, when readings are again made and compared with former findings. This process is repeated sometimes continually for several minutes and sometimes with pauses of several minutes between exercises. At the conclusion of a treatment and occasionally between exercises a phoria test may be made, when a somewhat altered balance will be observed due to the exercise. This change in muscle balance is usually in the desired direction, that of equilibrium, although often over-stimulation may carry the balance beyond normal into the opposite field. Such increased duction not alone subsides in the direction

of the normal but even recedes into subnormalcy. It is only after continued and systematic exercise that the innervations thus stimulated become permanent.

How to Build up a Weak Abduction

A *weak abduction* is almost invariably indicated by the imbalance *esophoria.*

To build up the *abduction,* prisms are set before the eyes as illustrated in Fig. 47. To accomplish this, it is necessary that the *external muscles* undergo a slow gradually increasing pull. Prisms are therefore rotated *slowly*—beginning at zero and increasing in power until diplopia develops—so that *apices* will turn *outwardly.* This means the *bases* must turn *inwardly.* The importance of observing this fact and the principle underlying it is the same as that explained in connection with "building up the adduction."

Beginning therefore at zero, the prisms are rotated so that the *bases* turn *inwardly* (apices and eyes outwardly), until the patient beholds two charts or two sets of letters, when rotation of the prisms must quickly cease and the readings on both prisms be noted. A consecutive repetition of this exercise, with or without pauses as circumstances may warrant, constitutes a treatment for building up the abduction.

How to Build up a Weak Sursumduction

A *weak sursumduction* is almost invariably indicated by the imbalances *right* or *left hyperphoria.*

Exercising the vertical muscles need seldom be attempted when the error is of a high degree. Two or more degrees of hyperphoria are generally but slightly benefited through exercise. Of the three conditions treated, adduction is the most amenable to exercise. Abduction responds next in order, while the hyperphorias are the least influenced by muscle exercise.

The author, however, always treats hyperphoria in the hope that a substantial response may in some cases be

elicited, and for the further reason that a slight improvement is better than none. Should prisms be ultimately prescribed, their powers may be thus reduced by whatever innervation has been developed through the deficient muscles. There is, in addition, the possibility that failure to arouse proper innervation through the vertical muscles is due not so much to an unswerving inhibition as to an education fostered by their special function which under persistent training may finally yield to the influence of treatment. This, however, is a problem which each may work out after his own judgment or experience.

As described under tests for sursumduction, to exercise the vertical muscles, rotary prisms are set before the eyes as illustrated in Fig. 48. Assuming that the right inferior rectus, the left superior rectus, or both, are deficient—which is the condition in right hyperphoria—a prism is *slowly* rotated before the right eye—beginning at zero and increasing in power until diplopia develops—so that the *base* will turn *upwardly* or the *apex downwardly*. This exercise, while exerting a pull on the deficient inferior rectus of the right eye, is, at the same time, pulling on the superior rectus of the fellow eye, thus dividing the treatment between the upper and lower muscles of the two eyes. The prism before the left eye may be removed or permitted to remain at zero, in which case it exerts no influence. Consistent repetition of this exercise constitutes a treatment of the inferior rectus of the right eye and the superior rectus of the left eye. By operating the prism before the left eye instead of the right, in the manner above described, similar treatment will be administered to the left inferior rectus and the right superior rectus, in which case the deficiency would be expressed by the imbalance left hyperphoria.

The vertical exercises, especially, must be conducted with utmost care and precision. Under normal conditions the vertical muscles overcome but 4 to 6 degrees of prismatic power. In a weakened condition they will hold even less,

and the first few degrees on the prisms are so closely graduated that the new operator, particularly, will rotate sufficient power to create diplopia before he is aware, and before the muscles have apparently been subjected to any influence.* Periodically, throughout treatments, phoria tests should be made and the duction condition noted after each exercise. This informs the operator what progress is being made during the work. The written record, however, should relate only to the maximum duction attained at each treatment. Other data, such as pertain to altered muscle balance, or anything else that appears of value to the operator, may be placed on record according to individual discretion. Such records need not be confined to the treatment of the vertical muscles, but are as essential to success when treatment is administered to the lateral muscles as well.

CHAPTER V

Oculo-Prism Treatment—Specific

Difficulties Encountered

1 When Making Muscle Tests—(Lost Images)

AS previously stated, oculo-prism treatment abounds in many snares and stumbling-blocks which often complicate the work and prove a source of difficulty and discouragement to the average beginner. In making muscle tests, for instance, with the Maddox rod before one eye, creating a red line, and the other eye observing a white spot, many patients often insist that but one image—the line or spot—is visible. The novice in muscle work is generally perplexed at this testimony. He knows that both a line and spot should be visible and cannot solve the apparent paradox.

*Since this was written, a later improvement in muscle testing apparatus (the phoroptor) has been devised and this difficulty is obviated in large part.

The facts are that when single binocular vision has been broken up by the Maddox rod, each eye roams in a direction guided by the imbalance. The situation is quite unusual to the patient. Fixing a single image with one eye or the other, he does not know how to cast about in the field of vision to locate the other image with the other eye. In fact he does not know that another image exists, unless the imbalance or state of innervation is such that the two images come reasonably close together in the central field of vision. The more attentively the patient's gaze rests upon one image, the less conscious is he of the other's presence. To overcome such a situation, two forms of recourse are available, both of which must generally be used. One of these is to instruct the patient to cast his view about the entire field of vision for the missing image. Should he locate this image but lose the former one in doing so, he will generally have less difficulty in re-locating by the same process the first image. In any event, he is now conscious of two different images and will soon learn to shift his gaze from one to the other without much difficulty. He is thus able to inform the operator of the relative position of images, from which information is determined the nature of the imbalance.

The other method, by which is facilitated the observation of both images, consists in rotating one prism, base *in* or *out*, before either eye (for lateral imbalances) until both images have been drawn closer together into the central field of vision. The direction in which bases are turned depends on what results are attained. If, for instance, after rotating the prism in one direction through what appears a considerable number of degrees, both images are not yet visible, it is safe to assume that the prism is being rotated in the wrong direction, which should then be reversed. It is quite certain that such rotation, if done gradually and slowly, will soon disclose both images, after which continued rotation in the desired direction will cause the images to

unite or intersect, and the degrees thus indicated upon the prisms will prove a correct measure of the imbalance. The proper thing to do, therefore, when *both images* fail to appear in the field of vision—after due effort on the part of the patient—is to rotate prismatic power, base *in* or *out*, *slowly* before the eyes, until the missing or lost image becomes also visible. An apparently inexplicable problem to the beginner in ocular muscle work will thus be quickly solved.

2 When Making Duction Tests—(Premature Diplopia)

Another source of difficulty in muscle work is to *correctly ascertain* from the patient's testimony *when diplopia has taken place*, as prisms are being rotated before the eyes. The error lies in the fact that diplopia often develops suddenly, upon what appears the slightest provocation, and one of the images flits outside of the field of vision without the patient being conscious of the fact. The result is that the operator, unaware of the occurrence, continues increasing prismatic power, expecting each moment to hear the patient declare that diplopia has taken place, until the exceedingly high power registered—with still no apparent diplopia in force—suggests the probability of some unforeseen error.

The patient has, under the circumstance, undergone diplopia without his own knowledge, while the operator, who is ignorant of this, is still attempting to create diplopia. That a *premature diplopia* had developed and that the difficulty is due to the patient's inability to give the correct testimony may not occur to the examiner who, looking for other causes, is compelled often to give up the work, baffled and discouraged. Under the circumstances the operator is really at fault. *Too great stress cannot be placed upon the importance of rotating prisms slowly, with utmost care and precision.*

The exercise of the extrinsic ocular muscles is a strange experience to the average patient. A degree of nervous excitement on the part of the patient accompanies practi-

cally all muscle treatments. This often reacts upon the innervational impulses so as to establish wild, irregular stimulations, throughout the guiding muscles, whose action becomes correspondingly irregular and uncertain. Persons under such conditions, subjected to the influence of rapidly increasing or variable prismatic power, often unconsciously undergo diplopia. Hence, in making duction tests or giving muscle treatment, the operator must develop that calm and deliberate poise, so essential to the technical worker. Treatment must never be initiated with a jar to the patient's sensibilities. One should glide into his work gradually, as only in that way can he successfully analyze or diagnose a state which deals wholly with mental or innervational impulses.

This offers the practical solution to the difficulty above mentioned when making duction tests or giving muscle treatments. *Premature* or *unconscious diplopia* will seldom occur if the operator is ever watchful in handling his prisms, and will turn on prismatic power, slowly and methodically, inquiring of his patient from time to time if a state of diplopia has developed. This becomes a part of the real technique in administering ocular prism treatment. It is being constantly alert in the patient's interest—quickly observing any change in the muscular status or the varying impulses—which constitutes efficient muscle treatment. As one progresses in the work, a fine sense of divination develops, and the operator in each case can discern personal characteristics or idiosyncrasies so necessary to perceive, when most efficient results are to be attained.

3 Negative Duction——(Periodic Diplopia)

One often meets another condition when administering muscle treatment which is both confusing and more difficult to treat. Similar to the condition of *premature diplopia*, often inadvertently produced by the operator when rotating too rapidly prismatic power before the eyes, is that of

periodic diplopia, temporarily created by an extremely low state of innervation which often permits a state of diplopia under any prolonged nervous effort or suppressed excitement. Such persons may quickly undergo diplopia while attending places of amusement, when upon public concourses, or in fact under any conditions which subject them to the influence of moving bodies or unusual action. It should not be surprising, then, that such patients, in the routine of a careful examination, may develop a temporary diplopia and the inexperienced operator, even less familiar with such an occurrence than the patient, may vainly strive to perform a duction test or give muscle treatment while the patient is fixing the chart with but one eye. One can readily see how useless such exercise must necessarily be. Nor, in fact, does any (positive) duction under such conditions exist. The state is one which is properly denominated *negative duction;* that is, a condition exists in which the deficient muscles register *less than zero duction.* Not alone are such deficient muscles incapable of withstanding a "prismatic pull" but during such *periodic diplopia* "prismatic help" is necessary even in order to maintain single binocular vision.

The amount of "supporting prism" thus necessary to establish single binocular vision is the measure of *negative duction* present. To build up such a state of muscular insufficiency to normalcy, it is first necessary to develop sufficient duction to compensate for the negative balance, after which further development goes to make up the regular positive duction.

To illustrate:—Let it be assumed that rotary prisms have been set before the eyes to measure *abduction.* With prisms at zero, no pull is exerted upon the lateral muscles and the patient should experience single binocular vision. With a normal abduction, 8 degrees of prism, *apices out* or *bases in*, before the eyes should not disturb single binocular vision. We find, however, that, under that amount of prism, diplopia does ensue. It is at once evident that abduction is not quite up to normal. With 7 degrees

before the eyes, diplopia, let us say, is still in force. Prismatic power is then regularly decreased to 6 degrees, 5 degrees and so on down to zero, with diplopia still remaining in force. At this point abduction necessarily measures zero as no prismatic power can be withstood by the external muscles. But the condition is even worse. Diplopia still exists. Hence it becomes further evident that "supporting prisms" will be necessary to help re-establish single binocular vision.

There is placed accordingly, say, one-half degree of prism *apex in* before each eye, making a total of one degree of prism before both eyes, and while the two sets of letters appear closer together, single binocular vision, it is found, has not yet been established. The prisms are then increased to one degree before each eye, making a total of two degrees before both eyes, when single binocular vision is at last found to maintain. It should be observed that not alone have the external muscles been unable to withstand diplopia *under stress of prisms*, nor yet *without any prismatic interference*, but that *two degrees of supporting prism* were necessary to help in establishing single binocular vision. It is this *supporting prism* which represents and measures the *negative duction* or insufficiency of muscles, and without whose support the state of *periodic diplopia* becomes manifest.

To develop a normal duction in such cases, one is compelled to first develop sufficient innervation to compensate for the *negative balance*, after which further increase in innervation may be applied toward the *regular* or *positive duction*. In the particular case above indicated, it would be necessary to develop two degrees of duction to neutralize the negative balance, and eight degrees for the normal *abduction*, making a total of 10 degrees. For practical purposes, however, a *total duction* which *approximates the normal* should suffice and prove sufficiently advantageous.

To discriminate correctly between *premature* diplopia, produced by the operator when rotating prismatic power too

rapidly before the eyes, and *periodic diplopia* due to a negative duction, one needs but insert a dark red glass disk before either uncovered eye and direct the patient's attention to the luminous spot on the distant chart at 6 meters distance. Should the presumed diplopia be *premature*, upon removing the prismatic influence, and supplanting it with a red glass disk, there will be apparent to the patient but one reddish spot (showing that fusion has taken place, *i. e.*, the white and red spots are superimposed, and no diplopia now maintains). Should, however, the condition be one of *periodic diplopia* (real temporary diplopia), then the patient will behold two distinct spots, one dark red and the other white, showing that the diplopia though temporary is real and in force.

Periodic diplopia, while more difficult to handle than the ordinary cases of subnormal duction, offers nevertheless an excellent field for muscle treatment. While the results may not be expected to be as uniformly successful as in the lesser disorders, success, so achieved, is more clearly pronounced and the patient generally is most appreciative of the service rendered. The author has had signal success in several such cases.

Treating Fixed Deviation or Tropia

While the author has personally had no opportunity to treat fixed deviations (tropia), he recalls one case of exotropia which a fellow-practitioner has handled successfully in a child eleven years of age, by means of training prisms. This case presented itself for muscle treatment as a last resort prior to undergoing a proposed tenotomy. The possibilities for muscle treatment thus uncovered are assuredly promising, to say the least. The abundance of lesser muscular deficiencies available, however, offers such a prolific field for the refractionist's service that only those who wish need occupy themselves with cases more responsive to oculo-prism treatment than the one just mentioned.

Muscular Conditions Met in Oculo-Prism Treatment

The general routine for exercising the extrinsic eye muscles has been so copiously covered that it is hardly necessary to re-state the process. However, to handle satisfactorily the entire range of muscular or innervational anomalies demands prolonged study and continued application. To refer to a few types, therefore, should prove interesting as well as helpful. As in ordinary refraction, high errors are more easily discerned and hence more readily corrected; so, in muscle work, are the higher and more pronounced insufficiencies more easily perceived and more palpably treated. For, as the lesser optical errors seem the more elusive to refractive correction, so do the lower muscular anomalies seem more intangible, hence less certain of being successfully handled. Similarly, as high spherical errors may be complicated by accompanying high astigmatic errors, so may a high lateral muscular insufficiency be complicated by a substantial co-existent vertical imbalance, thus mutually creating a source of difficulty most perplexing in the proper determination or correction of the muscular anomalies.

Uniformly Low Duction Throughout the Lateral Muscles

In the variety of muscular insufficiencies to be found, there is one condition which is particularly deceptive to the average beginner. It is the state of uniformly low duction throughout the lateral muscles. Though the balance between the internal and external muscles be one of equilibrium for distance, there often exists a uniformly low state of innervation throughout both pair of muscles which, for near work at least, demands special attention. The following will illustrate: The normal relation in duction between the internal and external recti muscles is generally accepted as 3 to 1, *i. e.*, 24 degrees of adduction to 8 degrees of abduction. Should the adduction in a given case be 9 degrees and the abduction 3 degrees, this relationship or rating remains still unimpaired, and distant vision is ac-

complished comfortably, while a distant phoria test further indicates a state of muscular equilibrium. All appearances, so far, are that of the ideal muscular state.

At the reading distance, however, where convergence must be brought into play, 9 degrees of adduction will hardly suffice to meet the requirements for nervous energy at near

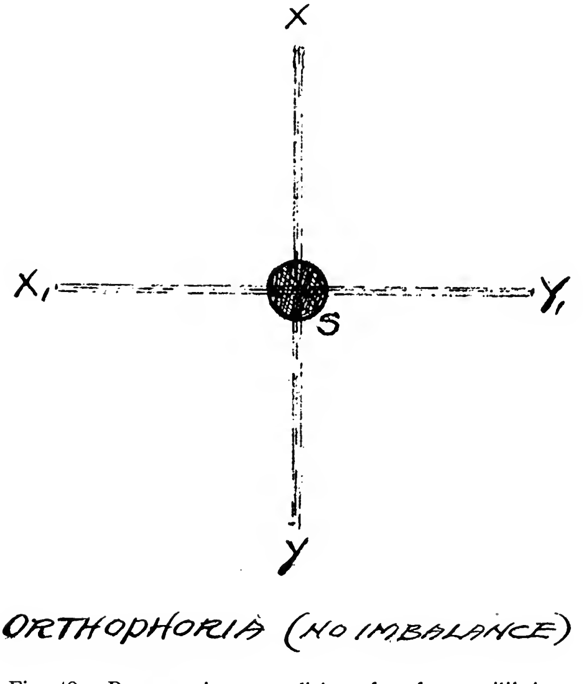

Fig. 49. Representing a condition of perfect equilibrium in all meridians.

work. Stimulating innervation through the internal recti muscles by means of prisms, and thereby raising the duction of these muscles, becomes quite imperative. Having substantially accomplished this, it then becomes apparent that the distance balance has been thus disturbed, and the condi-

tion of esophoria is now manifest. One must proceed then, in like manner, to build up the abduction to the point of muscular equilibrium. Assuming that adduction had been raised from 9 degrees to 18 degrees, it becomes necessary to similarly raise abduction from 3 degrees to 6 degrees. In this way, uniform innervation has been developed whereby the condition of distant equilibrium has been undisturbed and the requirements for close work have been better satisfied. When possible or convenient, a higher state of innervation than just indicated should be developed throughout the lateral muscles. The above increase, however, will generally suffice to give pleasing and satisfactory results. The confusing element in the condition described will be found in the fact that the distant phoria tests show no imbalance, and the near tests are too often omitted, or when made, fail to have much significance to the beginner in his limited understanding of normal and abnormal states. The necessity of making the duction tests, both near and distant, in all cases, regardless of muscle tests or superficial evidence, becomes apparent. It constitutes, in fact, practically the court of last resort in ascertaining the true muscular status.

Treating Lateral Imbalances when High Vertical Imbalance Co-exists and *vice-versa*

A condition generally troublesome to treat is that of a substantial imbalance existing simultaneously in both the lateral and vertical muscles. It is this type of imbalance which, though undergoing fusion in one meridian, is still incapable of effecting complete fusion by correcting the diplopia in the meridian at right angles as well. To treat such cases as one would the ordinary type is generally quite impossible. To exercise the lateral muscles, for instance, while vertical fusion is unsteady, becomes a difficult and uncertain task. The most intelligent and discerning patient cannot state definitely when lateral fusion takes place, while vertical diplopia tends to exist, inasmuch as proper fusional

impulses may then be considered impaired, and the accurate alignment of both images in a vertical line or plane is indeterminable on account of the vacillatory character of images at the command of the variable impulses.

In view of these facts, the author, in his own practice, has found it advisable to *temporarily correct* one of the imbalances, while *administering treatment* to the other muscles. Since the lateral muscles are more susceptible to exercise, it has been his custom to first *correct* the vertical imbalance and *take up treatment* of the lateral muscles. Next in turn, the vertical muscles are similarly *treated.*

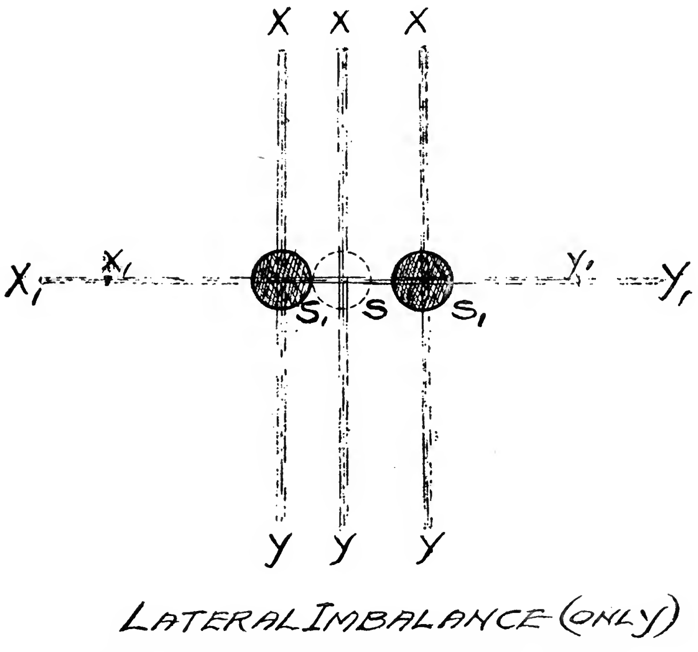

Fig. 50. Representing a condition of lateral imbalance

Correcting a muscle imbalance has quite a different meaning than *correcting a weakened state of duction.* In the former

case, the *imbalance* or *weak muscle* is merely *supported* by prisms, thus converting *artificially* or *temporarily* an imbalance to a state of balance. In the latter case, however, the impaired or deficient muscle is *exercised with prisms*, and

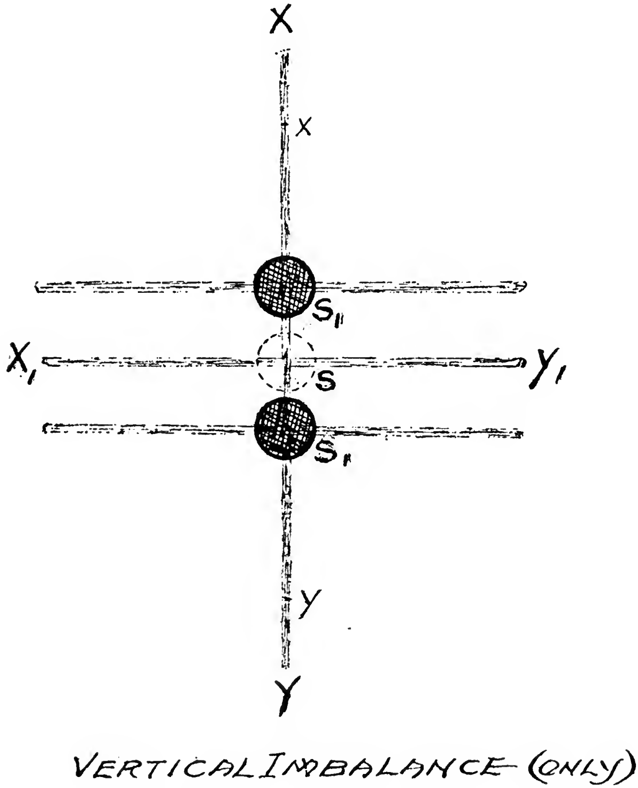

Fig. 51. Representing a condition of vertical imbalance.

developed to its normal power, thus establishing a state of *permanent equilibrium*. This distinction is drawn in order that the reader may understand the meaning of "*correcting* an *imbalance* while *exercising* the other muscles." When

the vertical imbalance is thus *corrected* before exercising the lateral muscles, the *vertical* diplopia has been temporarily eliminated by the *supporting prisms*, and free rein given to

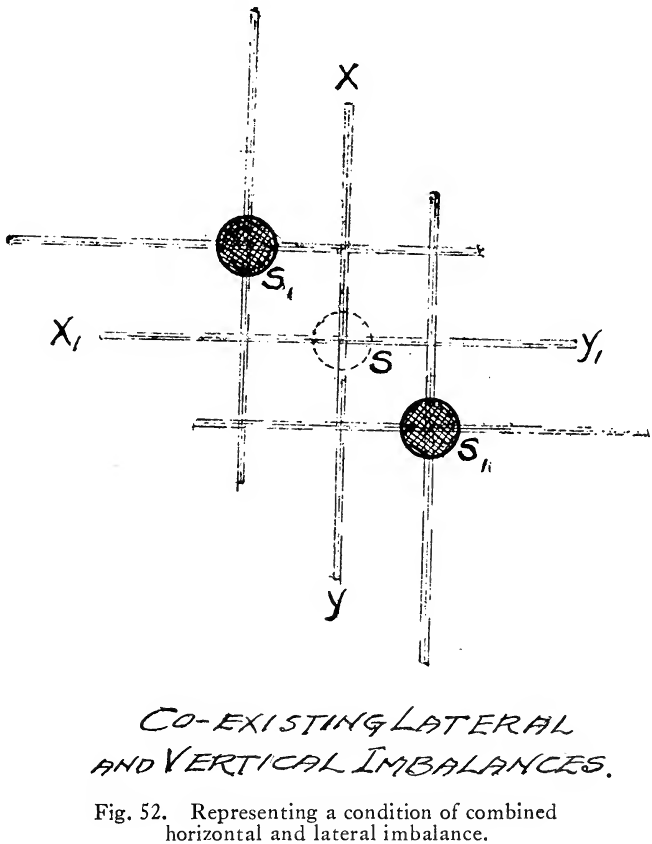

Fig. 52. Representing a condition of combined horizontal and lateral imbalance.

the exercise of the lateral muscles unhampered by vertical diplopia. To more clearly illustrate, we will refer to Figs. 49, 50, 51 and 52.

Fig. 49 presents a case of perfect equilibrium in all meri-

dians. A single spot S is observed at the intersection of the vertical and horizontal planes X Y and X_1Y_1, indicating single binocular vision. Fig. 50 illustrates a case of lateral or horizontal imbalance, with no vertical imbalance present. Fig. 51 shows a case of vertical imbalance with no lateral imbalance present. Fig. 52 presents a case such as previously described, in which both horizontal and vertical imbalances co-exist simultaneously. Referring to Fig. 52 one will more easily comprehend the purpose of the steps as formerly outlined.

In first correcting the vertical imbalance by means of prisms, the images S_1 and S_1 are fused vertically, *i. e.*, brought into the horizontal plane X_1 Y_1, when the condition is reduced to that of lateral imbalance as expressed in Fig. 50. The horizontal balance and duction tests may now be made, and exercise applied to the lateral muscles while the vertical imbalance is held in check with correcting prisms. Similarly, when it is desired to exercise the vertical muscles or measure their balance and duction, the horizontal imbalance—if any yet remains after exercise—S_1 and S_1 is corrected by means of prisms, so that the images S_1 and S_1 fuse horizontally and are brought into the vertical plane X Y. The condition then becomes one of vertical imbalance as represented in Fig. 51, after which muscle and duction tests may be made and muscle treatment properly administered. A somewhat complex situation is thus simplified and treatment may be applied as readily as in the simpler forms of imbalance.

It is, therefore, but necessary to remember that, in order to eliminate the vertical imbalance while measuring or exercising the lateral muscles, a prism is temporarily rotated before either eye, *apex up* or *down*, as necessary, until the two images S_1 and S_1 merge into the horizontal plane X_1 Y_1. This temporary prismatic correction remains in position while the lateral muscles undergo exercise. Similarly, when the vertical muscles are to be exercised, the horizontal imbal-

ance is temporarily corrected by rotating into position prisms *apices in* or *out* before one or both eyes, until the two images S_1 and S_1 are brought into the vertical plane X Y; this prismatic correction remains in position while the vertical muscles undergo exercise. In determining the proper temporary prismatic corrections it will be found advisable to use the Maddox rod in connection with the Stevens phorometer. Should the phorometer be left in position with the correction as thereby determined, it will be necessary, of course, that the Maddox rod be removed in order to continue with the test or exercise of the other muscles as primarily intended.

Prescott, Arizona

[To be continued]

Some Points in Handling Cases of Presbyopia and Subnormal Accommodation

being

A Lecture Delivered in 1921 in Glasgow, Scotland

Charles Sheard, Ph.D.

Synopsis

This paper is an attempt to analyze some theoretical and practical considerations and points of test in cases of presbyopia and subnormal accommodation. The topics, to the consideration of which the reader is invited, include the following:—(1) Accurate static refraction, (2) age no criterion in presbyopia, (3) influence of pre-existing errors of refraction, (4) necessity for tests upon accommodative resources, (5) anisometropia and amblyopia exanopsia, (6) inequality of accommodative amplitudes, (7) inaccuracy of data from near-point determinations, (8) improbability of reading corrections exceeding three diopters, (9) a twenty foot distance is not infinity, (10) astigmatism against the rule, (11) excessive convergence associated with the act of accommodation, (12) tests upon the ability to maintain accommodation, (13) presbyopia or hyperopia with exophoria or esophoria, (14) the amount of accommodation to be held in reserve, (15) discomfort and dissatisfaction arising from uncorrected vertical imbalances.

Introduction

SOME years ago Cross wrote with reference to handling cases of presbyopia, the following:—"Presbyopia is the one, so called, 'easy' ocular condition that is often the most difficult of satisfactory correction, for the reason that occupation, illumination, habit, pupillary distance, and innervation, or bodily vigor, are all factors to be reckoned with. Then, if combined with this, the ignorance and stupidity of many patients in answering questions is taken into consideration, it is easy to see why changes in reading glasses are so frequent." And Gould some twenty years ago wrote:—"When I began practice I did as I had been taught regarding the correction of presbyopia. Text-books, teachers and general custom agreed that presbyopia began some time

after forty. There was a rough rule wandering about that plus spherical lenses of one diopter were needed in forty-five-year-old-patients, twos at fifty, threes at sixty. This was about the time of the 'Punch, brother, Punch with care, a blue slip ticket for a five-cent fare, etc.' Actual dealing with presbyopic patients soon brought me up sharp. Rules like those of the street-car conductors would not work out in the oculists' office. If any rules at all were admissible they had to be of a different kind from those of the textbooks; in some ways far more definite, in others more indefinite."

I think we will all agree with Cross and Gould in their main point of contention in cases of presbyopia and that is this: that they are often among the difficult rather than the easy ocular cases from the standpoint of giving satisfaction and comfort, as well as relieving what we may term "nerve-drain" in hundreds of cases of early presbyopia or the younger person of premature presbyopic condition. And I believe also that we ought to bear in mind the facts which Cross briefly recited, for habit is the destroyer of our resiliency and adaptability and years are the destroyers of our physical and nervous constitutions, for we all of us begin to die at the moment we are born. The older we grow the more susceptible we are to annoyance and to the fatigue and that which we could do with ease in our twenties we do either not at all or else with rather rapid exhaustion as we proceed into middle life.

1. Necessity for Care in Static Refraction

In the first place, then, let it be stated that we believe the static refraction, upon which the presbyopic correction should be based, must be carried out with care. When there is youth and a large range of accommodation, the refractive error may not produce the injury or ill-effects which occur in the presbyope. This is self-evident you say; and yet many fail to appreciate its significance. And I feel

that it is rather more appreciated in America than in Europe. Possibly mathematical percentages mean little or nothing in ocular errors: we know that a low degree of astigmatism may produce reflex symptoms and not interfere with vision whereas a large amount may have no accompanying reflex symptoms and yet markedly affect visual acuity. Still percentages are of significance when used in showing the likelihood of an error or anomaly of refraction, such as hyperopia, being carried by the function of accommodation. For an error of half or three-quarters of a diopter of hyperopia in a young person of twenty, with an amplitude of accommodation of eight or nine diopters and leading an average existence, is commonly born without discomfort since the reserve accommodation is large. If this same error existed in a person whose amplitude of accommodation was three diopters, we are likely to have noticeable results including much dissatisfaction and discomfort on the part of the subject for the reason that such a continuous drain upon the low accommodative resources cannot be born without untoward symptoms. Of course, nature may pursue one of two courses; either the strain upon the accommodative resources may be too great and the resultant fatigue too marked, such that the accommodative mechanism fails to correct the error with the result that the possessor does not see *clearly* and *distinctly* or, on the other hand, the desire for keenness of vision may be satisfied but at the expense of the function involved and with *subsequent reflexes* and other evidences of nature's rebellion. We so often encounter those who are suspiciously presbyopic—especially in the early stage—who either feel that their vision is failing, since they complain of the fact that they cannot see as well as they once did, or else complain of nagging sensations about the eyes. Of course, all reflex symptoms are in the early presbyope aggravated from close-work, but we have many cases in which cessation from close work and an out-of-door life do not remove the strain upon the accommodative

muscles and centers, and again we have many who wear their glasses for reading purposes who do not get satisfactory eye comfort. There is much, therefore, to be said in emphasis of this first point in the case of presbyopia and those having subnormal accommodation, to wit: a careful determination of the static refraction. Carelessness in placing the axis of a correcting cylinder, the failure to get the accurate amount of the refractive error, failure to determine the small anisometropia which so frequently exists in those who have come to the presbyopic stage without ever having been inconvenienced with glasses, nearly always are more disastrous in the class of cases we are discussing than in eyes with plasticity and with activity of neutralizing powers, and which very gratefully receive assistance approximating the proper amount.

2. Age No Criterion for Presbyopia

In the second place, age has nothing to do *per se* with *presbyopia* and the necessity for giving presbyopic corrections. Or we may state our premise in another form; presbyopia is a misnomer, since age has nothing to do in and of itself with the condition of a pair of eyes as to their acuity conditions or their amplitudes of accommodation. Presbyopia in fact exists whenever, after the static refraction has been determined and the eyes equipped with proper corrections, the eyes are unable to maintain the act of reading with distinctness, ease and comfort at the point desired. Presbyopia, therefore, is a condition in which the demands upon the accommodation at the customary near-point of working, reading or other close-work are excessive and cannot be continuously supplied through the normal act of accommodation, resulting in the ability to see details distinctly, or if seen distinctly, with discomfort and reflexes. To be sure, this depleted amplitude of accommodation may be due to hardening of the lens substance, to weakness of ciliary muscles *per se*, or again to impairment of inner-

vational centers or obstruction to the delivery of nervous impulses from the appropriate nuclear centers. Since presbyopia is a misnomer and since that which should be classed as presbyopia—either normal or premature, natural and in the course of events, or pathological—is best defined as a condition of depleted amplitude of accommodation such that, with far-point placed at infinity, close work cannot be pursued with comfort and ease, we feel that it would be a good thing if the term were to be regulated to the pages of history and reference made solely to *accommodative resources* and *demands*.

3. Influence of Pre-existing Errors of Refraction

In the third place, however, the age at which we may ordinarily expect to prescribe presbyopic correction does depend somewhat upon the pre-existing error. The old rules, you will remember, gave forty-five as about the earliest presbyopic age to be normally expected. But all such rules are obviously absurd. For one thing, the static refraction will be an important factor; that is, the presence or absence of hyperopia, emmetropia or myopia as a static refractive condition will obviously play a part in determining the time at which an average pair of eyes will be forced to seek assistance in doing close work. Evidently this point with reference to presbyopia is again one of accommodative demands and accommodative resources. To be sure, a static uncorrected hyperopia will call for what is commonly called presbyopic corrections earlier than a condition of emmetropia and earlier again than in myopia, all other things being equal. Astigmatism creates greater indefiniteness, especially if unequal or nonsymmetrical in the two eyes. And again, we may ask whether or not the correction of the static ametropia has any influence on deferring the necessity of a presbyopic correction. It certainly does, for the correction of hyperopia prevents overdevelopment and hypertrophy of ciliary muscles and

makes a pair of eyes function approximately as though emmetropic. Exercising the ciliary will also, so Savage claims, defer the day of depleted resources for close work. Possibly the myope is the only one who, without his distance glasses, may be able to proceed without a reading correction, but his state is as bad as that of the hyperope who enjoys distance vision but cannot get along without a reading correction. We have every reason to believe that proper functioning of any organ will contribute to its longevity and to its ability to do its work without assistance; we have every reason to believe that the early correction of hyperopia and astigmatism and the constant wearing of such corrections will aid in deferring the day of accommodative assistance in close work.

The onset of presbyopia demanding correction may be delayed without doubt beyond the normal age by hypertrophied accommodation. This abnormalism of excessive accommodation is, of course, due to the over-functioning of the ciliary muscle and possible abnormally retained elasticity of lens. But excessive use of any organ or abnormally prolonged use always produces a disastrous reaction. The excessive use of accommodation in presbyopia causes eyestrain and all of its reflexes. The eye itself and the nervous system must suffer. I think we need to teach our people that these stories as to ability to read at sixty without glasses and the accounts of old people reading without a pair of spectacles are largely boasts; that in the end one of two things happens in general: reading and other close work are given up or the day comes when the eyes rebel and refuse to do such work and "all the King's horses and all the King's men cannot set them together again." Ah, yes indeed! You must have had them; eyes that had little or no static error, that were keen at distance seeing and that belonged to a proud possessor—falsely proud—who needed accommodative assistance in close work and yet put off the day of salvation. And have you not seen some

of these back, veritable wrecks, with eyes hypersensitive, literally beaten to death—and it has taken hours of your time and weeks of your patience and sympathy to help nature repair the damage which could have been so easily prevented. Indeed, a condition of presbyopia to one who has been blest with a splendid seeing, well-functioning power of eyes, may well-nigh be his ruination, and it takes skill and science on the part of the practitioner to induce such a person to do that which is right by himself or herself.

4. Necessity for Tests upon Accommodative Resources

Fourthly, the amplitude of accommodation, the accommodative reserve and the amount of correction possibly needed in the best interests of the ocular functions are matters of test and not of age or of rule. Every pair of eyes is a law unto itself. True it is that we have a series of tables due to Donders, Landolt, Risley, Duane, Jackson and others which give us their findings as to the age-accommodative amplitudes and far- and near-points. In the main these agree, when the various methods of obtaining data are taken into account. Some of these methods involve nearest point of ability to read distinctly, others to just decipher or count dots, still others involve the use of concave lenses. But they are, like acuity charts such as that of Snellen, simply *averages* and give a *standard* or something by which we may judge as to whether the pair of eyes we have under test is below, equal to, or apparently superior to the average eyes from the *accommodative* standpoint. To my mind Donders never intended anyone to believe that every person who, for instance, was fifty years of age, should be presbyopic an amount such as he specified, but rather did he, we believe, desire to present such a table, carefully prepared from the best data available, to show the *average* condition and thereby enable us to judge of the significance of our particular set of data obtained in the light of the table of averages. Neither do I believe that such a table should be used in conjunction

with the finding of the near-point as is involved in the following procedure: Take the nearest point monocularly at which *details* can be distinguished; convert this into the dioptric equivalent; take the difference between this finding and the amplitude of accommodation given by Donders, for instance, for emmetropia at the age of the person under test; this difference will then be the distance correction. Presumably interrelationships between accommodation and convergence are eliminated, since monocular tests are made, but the method as a whole is of no particular value. The first part is, however, for it gives us the amplitude of accommodation actually existent, without taking into account the ametropia. But the use of Donders' table and the taking of the difference of the two readings specified to represent the ametropia is obviously using such a table as an infallible standard and not as an *average* which may be reasonably expected. Donders' and other tables of amplitude of accommodation, far- and near-points and so called presbyopic corrections are, to my mind, exactly analogous to life insurance tables which show the average expectancy of life at the age specified; there is no guarantee or assurance of such existence.

5. Anisometropia and Amblyopia Exanopsia

Fifthly, the presence of a considerable amount of anisometropia as well as the presence of amblyopia exanopsia in one eye may considerably modify the presbyopic correction to be given. We have had in our own practice many cases in which the difference of refraction in the two eyes is so marked that evidently the major portion, if not the whole of distinct seeing, both at distance and near, has been accomplished by one eye. If such conditions are found in early years and corrected, quite generally the accommodative functions in the two eyes will be found to work together in unison. In such cases little difficulty will arise except possibly in the matter of the

ability to give equality in ability to read, which condition may be impossible, especially when one eye is wearing a high astigmatic correction. But in cases in which the ametropia is marked and in which the vision has been very keen in one eye, so much so that often the possessor fails to be appreciative of his low vision in the other eye, trouble often arises in presbyopic corrections in which any attempts are made to give the presbyopic corrections in addition to the full or nearly full static refractive corrections. The reason for this is fairly obvious; for the retinal images are so dissimilar and habit so strong that it is almost impossible to give scientific prescriptions without causing extreme annoyance to the person examined. Pages are lop-sided and the highly anisometropic or amblyopic eye, not being accustomed to the act of binocular vision and being unaccustomed to its continual use in vision, rebels and things are worse than in their former state. We remember very clearly the case of a woman of about 60 years, who said she had possessed no use of one eye since a child. After the correction of the high error we found it possible to give V=20/20 and after giving proper additions for reading to both eyes left this woman happy in the use of her two eyes. But the outcome was that which we feared, for she was unable to use her glasses for any but brief periods of time and we had to resort to methods of slowly restoring the amblyopic eye to normal functionings. The exclusion of one eye from functioning always brings most difficult problems. But, by occluding the good eye and giving a partial correction to the amblyopic eye, it is often possible to, in the course of time, slowly restore it to normal vision with comfort through proper correcting glasses, and to then proceed to harness the eyes together in binocular vision and in reading. I am positive that many eyes in the presbyopic stage, which are to be classed in the kind of case we are discussing, come to every practitioner and that much more could be done for them than is generally attempted.

6. Inequality of Accommodative Amplitudes of a Pair of Eyes

In the sixth place, inequality of accommodation in the two eyes is a matter which should receive greater attention than it does. There is no reason, *per se*, for assuming that the amplitude of accommodation in each eye is the same and that presbyopic reading corrections should be prescribed as O.U. +1.00 or +2.00, etc., any more than there is reason for believing that the static refractive error will be the same in both eyes. To be sure, in general such is the case, but the law of averages and the *general* condition has no business in ocular refraction. The finding of inequalities in accommodative amplitude in presbyopes serves one or the other of two purposes:—(1) If an inequality of reading correction is found in order to give equal range and reading amplitude, suspicion may be cast upon the inaccuracy of the static findings in one or the other eye. This leads to our emphasizing the importance of making comparison tests to see that each eye, fitted with static findings, has equally good or keen visual acuity where such is possible. This is an important test and is too often omitted. Quite often, then, inequality of accommodative amplitude or apparent reading addition is found to be due to inaccurate distance findings and corrections. (2) If a genuine difference of amplitude of accommodation does exist, this immediately shows the necessity of a difference in reading additions and furthermore is a cause for making further examination as to any pathological conditions which may be at the seat of the lowered amplitude in the one eye. This inequality of function may, therefore, be due to anisometropia, right-eyedness or left-eyedness, peculiarity of occupation, of heterophoria, of monocular disease or of injury. The manner of procedure depends, of course, upon all the findings.

7. Fallacies of Near-point Tests

As a seventh point, it seems to me to be a fallacy to say that presbyopia exists if fine print cannot be read at

eight inches. We often find this statement in print, but it is simply another evidence of an arbitrary rule which may or may not be applicable in a given case. In the first place, the distance at which print is read or the close work conducted is more of a criterion of the necessity of a reading correction. The near-point, with emmetropia for distance, or static correction worn, may easily be as low as ten inches and yet no reading correction be needed, since many persons do their close work at considerable distances from their eyes, for instance at 16 or 18 inches. If the amplitude is four diopters, and one-half of it only is constantly demanded at close work, and if the periods of application are not too long, we often find comfort and satisfaction without reading corrections. Many other factors than a mere determination of a close-point with an arbitrary standard set as to necessity of presbyopic correction enter into such determinations; as, for example, the character of work, hours of application, general bodily health, condition of nervous system, etc. Donders laid down a much simpler, more important and elastic law when he wrote: "*The accommodation can be maintained for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably great.*" With this as a practical clinical basis it seems to us a far saner procedure to find the positive part of the relative range of accommodation at the point of customary reading and close-work. Such positive portion of accommodation is determined through the use of concave lenses, the test object used being held at the usual reading distance. And again, this matter of an arbitrary eight inch point of reading fine type leads us into serious trouble for the reason that, due to enlarged retinal images, narrowed pupils and even narrowing of palpebral fissure, fine type may possibly be read at eight inches when a genuine presbyopic condition exists and is in need of attention. My own feeling is that,

after all, ability to read fine print at a close point is not as accurate a test as we might wish it to be. Chief of these objections is that it gives us, under circumstances which do not introduce other inaccuracies or fallacies, a measure of the maximum ability, as judged by the test, on the part of the accommodation rather than giving us a test upon the nearest point at which accommodation may be exercised and maintained. Furthermore, it appears to me to be an abnormal kind of test, for the reason that accommodation is not normally called into play at any points closer than the customary near-working point.

8. Improbability of Reading Corrections Exceeding Three Diopters

And further, as our eighth point, we do not believe that there is ordinarily any reason for adding more than +3 D.S. as the limiting value, even in cases where the near-point is 13 inches, as a reading correction in presbyopic cases. When we hear of +4 D.S. or amounts approximating this as additions for reading in presbyopic cases we suspect one of two possibilities; either (1) the static error has not been properly corrected either through negligence on the part of the examiner or possible inability to cause full findings to be accepted with comfort or (2), in conditions of lowered acuity the higher reading corrections may be of service as magnifiers, giving large form to letters although leaving them with less distinct outlines. We do not believe that the first reason given is in general a valid one as the final outcome of a case, but may possibly have to be resorted to in rare cases in initial corrections. There is the possibility that the second reason assigned may be of real value in an occasional case. We have to say that we look with suspicion upon any set of findings in which the reading addition for the customary reading distance of 12 or 13 inches is greater than 3 D.S.

9. Twenty Foot Test Distance is Not Infinity

In the ninth place, we must point out the fact that, while we have just urged the point that distance corrections in presbyopic cases are too often only partial corrections, considerable care must be exercised in distance fittings of presbyopia to insure the removal of that slight fog or haze at distance so often complained of, where in our offices we find the acuity through such glasses to be nearly 20/20 or slightly better. The common complaint is that people are readily distinguished at 10 feet but not at 30 feet or even 20 feet; the preacher at church, the distant scenery, or what not, are not just as clear as desired. Of course it is possible that such exactness is not obtainable in many presbyopes due to changes which come with years. But when our clinical tests show V = 1 or slightly better we may be assured that such complaints are genuine. A moment's reflection will lead to a solution of this matter, for 20 feet is not infinity but is represented by a dioptric value of 0.16 D.S. This is close to the quarter-diopter spheres of our trial case contents. We feel that the procedure should be to carefully determine full corrections giving V = 1 and to then undercorrect each eye for distance by O.U. 0.25 D.S. Another easy and valuable test, where possible, is to have the patient look for detail in some fairly distant object with full corrections and when reduced by a quarter diopter. When an appreciable difference exists in keenness of vision, the response will be rapid and most assuring.

10. Astigmatism "Against the Rule" in Presbyopia

As a tenth point, we are calling attention to the care and judgment needed in the matter of the incorporation of corrections for what is commonly called astigmatism against the rule in presbyopic cases. It is a fairly well-known fact in physiological optics that as a general rule a condition of no astigmatism in early years gives way to an inverse or against-the-rule astigmatism or again a small amount of

with-the-rule-astigmatism may disappear or even become inverse in its character. We believe it is very desirable from the standpoint of comfort and general satisfaction to presbyopes that against-the-rule astigmatism be under-corrected and in low amounts—quarter diopters—be omitted in general. There are those I am sure who will disagree with this suggestion but our experience is in the form of the proposition as we have presented it. As a general matter of optical practice reading glasses are not properly angled with respect to the eyes and this introduces in fairly large presbyopic corrections a cylindrical effect to serve as a correction of low astigmia against the rule. Furthermore, looking obliquely through a lens and the use of the peripheral portions or parts of the lens remote from the center will introduce a cylindrical effect. We have seen, for instance, cases in which findings from every scientific procedure indicated +1.00 cyl. ax. 180 in conjunction with the spherical findings. If such correcting lenses are made up, it is our experience that they will always be annoying and will be a source of complaint, which can be remedied by the reduction of the cylindrical power to +0.50 D. cylinders. It will be apparent from the arguments which have been presented that we are not arguing for the replacement of good scientific findings with arbitrary changes, for the reason that the laws of physical optics indicate to us that certain conditions present in presbyopic corrections afford cylindrical effects offsetting a certain amount of astigmatism against the rule. We may also be permitted the citing of the inadvisability of giving a cylindrical correction of low amount, especially in presbyopic corrections, when such is found to exist in one eye only.

We pass on to consider the indications of the early stages of presbyopia or need for additional assistance in doing close work. We shall bar out from the discussion cases which may be properly classed as abnormal subnormal accommodation as distinct from natural or normal insufficiency

of accommodation. The remarks which follow, however, are in general applicable to all conditions of such insufficiency.

11. Excessive Convergence Associated with the Act of Accommodation

As the eleventh consideration, therefore, we may point out the quite frequent occurrence of that which we have designated as overconvergence as associated with the act of accommodation. In other words, when the accommodation is active in the process, for example, of reading, and the act of fusion is annulled, tests often show an accommodative overconvergence, whereas muscle tests at distance show a slight divergent or exophoric condition. Such a condition can arise from excessive innervation to the ciliary to produce the actual accommodation physically and physiologically demanded and such tests may therefore be an important clue to the necessity for additional reading corrections. The giving of additional half or one diopter spheres in such cases will often show an immediate reduction in the overconvergence, thus indicating that a better innervational condition has been established both from convergence and accommodative standpoints. Near muscle tests may, therefore, be very valuable in aiding us in our judgments as to proper procedure.

12. Tests upon the Ability to Maintain Accommodation

In the twelfth place, the test as to the ability to sustain accommodation is a most useful criterion in our handling of cases of suspected presbyopia. We objected earlier in our deliberations to following any arbitrary rule such as one which stated that the presbyopic state existed if the nearpoint was not equal to or less than eight inches. The ability to sustain accommodation is a much more instructive and valuable test. We have often had pairs of eyes, which demonstrated their ability to read fine print or, better still, distinguish detail at eight inches or less, but

which could not maintain any such standard. To my mind the procedure of finding the maximum amount of pull which any muscle can exert momentarily is a poor criterion of its ability to carry on work demanding the expenditure of considerable energy over a continuous period of time. As we view it, a test of my ability to register on a scale my limit of pull is no criterion as to my endurance. One pull may be indicative of ample strength only to be negatived by subsequent low registers under repeated trial. Many eyes will show such performances as to their ability to sustain accommodation. We have seen pairs of eyes which, under initial test, showed a maximum amplitude of accommodation of five diopters, but which, if you please, "petered out" very quickly and gave constantly decreasing amplitudes of accommodation under very few trials. For example, a pair of eyes, reading fine print at 13 inches, may initially overcome —2.5 D.S., indicating a total of five and a half diopters of accommodation. The limit having been reached the accommodation may be relaxed and everything become blurred. Repeated trials showed that —2 D.S. and then —1.5 D.S. can be overcome, possibly concluding with evidence indicating an ability to sustain an accommodative act involving four diopters, or slightly better. Such a test indicates the need of accommodative assistance in order that close-work may be carried on efficiently and with comfort, whereas a single near-point test would lead to the conclusion that no such assistance was needed. The distance at which the accommodative act may be readily *sustained* is a better criterion than is the determination of the distance indicating maximum amplitude of accommodation.

13. Hyperopic or Presbyopic Corrections with Exophoria or Esophoria

As a further consideration—and thirteenth in point of order—we desire to call attention to the doctrine which appears to have received wide acceptance, in America at

least, that in hyperopia with exophoric tendencies there should be, in general, a reduction of the correcting spheres and that in hyperopia with esophoria there should be correspondingly an increase or as full a correction as possible. Presbyopia, although due to depleted accommodation at the point of close work in contradistinction to abnormal or excessive drain upon the accommodative resources because of a hyperopic error of refraction, may, by virtue of the fact that convex lenses are demanded as corrective agents, be classed as a form of hyperopia. Hence the general statement just recorded with reference to cases of hyperopia is also made applicable to presbyopic conditions. We are in accord, in both the general conditions of hyperopia and presbyopia, with the doctrine that full corrections should be given in such cases when esophoric tendencies are found, provided these esophoric tendencies persist also in the near tests. On the other hand, we are in disagreement with the doctrine of the reduction of hyperopic or presbyopic corrections, *per se*, when exophoria exists either at distant or near points. Quite commonly tests upon exophoria and esophoria are made at distance, *i. e.*, 20 feet, and the notion seems to be that a full correction or even overcrowding of hyperopic corrections should occur when esophoria is present in order that the heterophoric tendency may be allayed through suppression of the accommodation and that, on the other hand, an undercorrection should be given when exophoric tendencies are discovered in order that orthophoria or stimulation thereto may exist through allowing some accommodative action to persist. But the fallacy in the second part of this teaching we believe lies in the fact that each pair of eyes is a law unto itself and that specific tests alone, as performed with and without hyperopic corrections, will evidence the existence of any correlation between the heterophoric condition and the accommodative demands. For example, we have seen many cases in which O.U. +1.50 D.S. afforded (bin-

ocularly) V=20/20. When the tonic conditions at distance were investigated both *with* and *without* correcting lenses in turn such a condition as 3^{Δ} exophoria might exist. In such cases, it is quite evident that there is an inherent exophoria and that the same is not corrected by and has no connection with convergence associated with accommodation. And again, cases arise in which O.U. +1.50 D.S. give (binocularly) V=20/20, and which show no imbalance at distance without correcting lenses and possibly evidence 3^{Δ} exophoria with full correcting lenses, showing conclusively that an inherent exophoria is corrected or taken care of in such cases through the convergence associated with accommodation. A little consideration of these two sets of conditions, identical as to refractive error, as well as many others which arise in practice ought to convince us of the fact that the convergence necessary for binocular single vision at any point is not necessarily derived wholly through the act of accommodation, *i. e.*, in accompaniment with this act and therefore to be designated as *accommodative convergence*, but that the *fusion convergence*—under the control of the fusion centers—may be operative in many pairs of eyes to furnish the deficit as left by the accommodative convergence in order that binocular single vision may ensue at any fixation point specified. There are, therefore, many cases in which O.U. +2.50 D.S., for example, are apparently satisfactory as a reading correction—affording a sufficient reading amplitude and range with the best seeing region at about the customary reading point—and in which distance tests without distance corrections (if such exist) show a degree or two of exophoria or possibly orthophoria, but which, on the other hand, show high degrees of exophoria—eight, ten or twelve prism dioptries for example—when such tests are conducted at the reading point. Simple tests quickly demonstrate whether or not binocular vision through O.U. +2.50 exists at the reading point. If such vision does exist we are cognizant of the fact that bin-

ocular single vision in such cases as we are discussing was not central, *i. e.*, in accompaniment with or through the acts of accommodation and that the deficit in order that binocular single vision might exist was supplied through the positive fusion centers. And yet again, another pair of eyes may be under simultaneous observation and requiring O.U. +2.50 D.S. for reading purposes, in which tests will show either the full complement of convergence, necessary for binocular single vision, associated with the accommodative act or there may occasionally be a condition of over-convergence evidenced under dissociation tests. In concluding our comments on this point, it seems to us that many of the notions current upon the dependence and interdependence of accommodation and convergence need revision and that, to say the least, conditions of muscular imbalance at distance should have, *per se*, no weight in matters of modifying presbyopic corrections. The only scientific basis we believe is that which rests upon *data obtained upon the function or functions involved at the point for which fixation and accommodation are undertaken*. For the condition of dependence, in whole or part, and of independence, in whole or in part, of the functions of accommodation and convergence are as characteristic of a pair of eyes as our own facial features are characteristic of each of us individually. And if the convergence necessary for binocular single vision were obtainable only in accompaniment with the specific act of accommodation and as a necessary normal consequence of the act of accommodation *per se*, there would then be a solid basis for the doctrine of reduction of presbyopic and hyperopic corrections in conditions evidencing exophoria. But the convergence act with reference to any point of fixation may be accomplished through two functions, namely: *accommodative* and *fusional* innervations. As to the proportion of innervation furnished from each set of centers or by each source, we cannot guess but we can easily test and determine. One simple test

consists in suspending *fusion* through the use of vertically dissociating prisms and permitting the act of accommodation to take place for any desired distance through the viewing of a dot or a line of letters. Doubleness of images of test object used will accrue under this test and the amount of prism needed to align the dots gives a measure of the convergence deficit or excess (as the case may be) in association with the innervational deliverances to accommodation.

14. The Question of the Amount of Accommodative Reserve to be Maintained

And furthermore, as our fourteenth consideration, we desire to call attention to the fact that any arbitrary rule as to the amount of accommodative amplitude which should be left in reserve in any case of presbyopia is, in the last analysis, of little value except as being an approximation. We have frequently met with statements in articles and textbooks on this matter and the recommendation is either that one-half or two-thirds of the total amplitude be left in reserve. But surely it must be admitted that some pairs of eyes will need more and some less than any amount specified as a general proposition. We have already pointed out that such factors as fatigue and ability to sustain accommodation are most important in presbyopia as well as conditions of unnatural subnormal accommodation. We have conditions which are classified as painful accommodation and we often have accommodative difficulties of a characteristic type in neurasthenics or those who suffer from nervous derangements. We have, again, already pointed out the fact that a whipped and overtaxed accommodation, such as may exist in early stages of presbyopia or in abnormal subnormalcy of accommodation, may at times give rise to an overconvergence impulse because of the fact that the function of accommodation and convergence may be very intimately linked and very dependent upon each other, hence

demanding a considerable amount of accommodative suppression and leaving more accommodation in reserve than ordinarily, whereas if such a condition of affairs did not exist we should proceed otherwise. We know of no exact methods of procedure which can be recommended as giving us the data which are desired on this point. The history of the case, symptoms and complaints, furnish valuable indications to direct our attention to these possibilities. Furthermore, methods of dynamic skiametry when practised with fixation and observation in the same plane and when lens quantities are added until neutral shadows are obtained, furnish us most valuable objective data. The test by dynamic skiametry quickly and reasonably accurately indicates the lenticular assistance needed in presbyopia or in subnormal accommodation, provided lenses are added until a neutral shadow is obtained and if, furthermore, about three-quarters of a diopter lag of accommodation is allowed for in the ordinary case.

15. Discomfort Produced by Uncorrected Hyperphoria

In conclusion, and as our fifteenth point of consideration, we mention the importance of the correction of vertical imbalance in cases of presbyopia. We all have cases in which either bifocals are worn or else reading lenses for close-work are slipped on when needed, and the wearers report extreme discomfort and inability to engage in reading, desk-work, factory manipulations at close range, and so forth, for any but the briefest periods of time. Often such persons come to us armed with ten or a dozen prescriptions and with pockets filled with all kinds and sizes of spectacles, lenses and frames. In many cases we smile as we find the effective powers of the various pairs of lenses handed to us, or else compare the prescriptions delivered to us by these people. Possibly the distance corrections vary by as much as ±0.25 D. S. and small cylinders are either incorporated or omitted. The reading additions vary within a similar small range.

It is generally found, by questioning the patients, that some of these corrections have been given after the use of a cycloplegic and some without its use. To be sure, no two of them are exactly alike, but they quite evidently indicate that the examiners have all arived at virtually the same findings and have therefore "rung all the changes" possible in so far as distance and reading spheres or sphero-cylinders are concerned.

To be sure, it is possible that some incorrect sets of findings may have been obtained or improper judgments may have been exercised by previous examiners and that very radical changes are necessary in either distance or reading corrections, or possibly both. In many instances, conditions of convergence insufficiency at close points have not been discovered and the incorporation of small amounts of prism, base *in*, in the reading additions or glasses will solve the problem. And again, there are conditions of esophoria at both distant and ordinary reading points, when comfort can be given only through the use of distance corrections which may reduce the visual acuity or the use of reading additions of greater power than would normally be expected. But if, after a painstaking examination of all these and similar points, no suggestive clews are forthcoming and, therefore, no changes apparently to be made in the glasses being worn, a very searching examination (or even re-examination, if one has previously been made) should be made with reference to the presence or absence of a vertical imbalance both at distant and close fixation points. A genuine vertical imbalance of one prism dioptry, especially if it reveals its presence at both distant and reading points, is worthy of very careful consideration. It is obvious that, in case a small vertical imbalance exists, the vertical fusion centers will be constantly called upon to furnish nerve energy to accomplish binocular single vision. There will, therefore, be—if the amount of vertical imbalance exceeds one-third to one-fourth of the total fusion reserve as

evidenced by the duction tests—a drain upon the appropriate fusion centers, such that binocular single vision is an oscillating or vacillating act. There is, as a result, soon set up a condition in which the binocular visual acuity, both at distance and reading, is apparently reduced and distant letters and type pages carry a slight haze or blur. This is due to the fact that binocular single vision almost—but not quite—exists and the images as seen by each eye are not quite superimposed. It is obvious, then, if this condition of affairs exists, that the source of the disturbance and inability to carry on close work or to even see distant objects in sharp detail is not due to accommodative troubles but to vertical imbalances. Careful tests for vertical imbalances are to be recommended in such cases as we are discussing and, after the correction of a considerable amount of the hyperphoria, comfort and satisfaction will generally be reported. We close the remarks upon this important matter with the statement that nearly all those who are making careful studies of the ocular muscles have come to the conclusion that conditions of hyperphoria should always be given a partial correction at least.

And, finally, subnormal, paretic, insufficiency of accommodation or premature presbyopia, as some have desired to call it, and even paralysis of the accommodation of a functional or reflex nature and not dependent upon organic disease *per se*, exist in a considerable number of young and those approaching the close of their mid-thirties. Time and space permit us only the comment that practitioners should make tests upon the accommodative demands and resources of every pair of eyes that comes under their observation and care, for age is no respecter of eyes any more than of other bodily organs and for the further reason that each pair of eyes is a law unto itself and is not amenable to any law of average treatment or correction, however true such dicta are in general.

Abstracts and Reviews

Some New Tests for Astigmatism

Ernest E. Maddox, M. D.

THE author presents two tests which afford the refractionist convenient and sensitive subjective tests for astigmatism. The original article as it appeared (*American Journal of Ophthalmology*, Vol. 4, p. 571, 1921), uses about as few words and as little space as could be asked for, therefore we have taken the liberty of quoting this article practically in full.

1 The "V" Test for Astigmatism

"For this test the capital letter 'V' is made to perambulate around the periphery of Snellen's small fan of lines, either with the hand, or better, with a string from a distance. (See Fig. 1.)

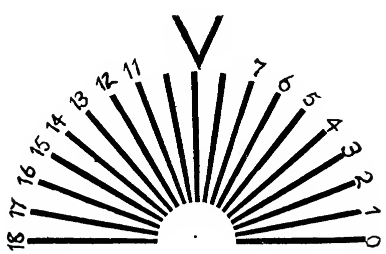

Fig. 1. V test with Snellen fan chart.

"The 'V' acts, firstly, as an *indicator*, and secondly, as a *confirmer*. As an indicator, it enables the surgeon to make

sure as to which ray of the fan the patient sees best, without the necessity of large figures, which lessen the simplicity of the chart to the patient's eye. Having found the ray, the 'V' is next used as a confirmer, to test the correctness of the patient's choice, for if the correct ray has been chosen, the two arms of the 'V' will appear of an equally vivid blackness.

"The 'V' should now be moved a little to one side, until a difference appears in the blackness of the two arms, and then to the other side in the same way. In each case the blackest arm will look towards the spot for the correct angle.

"If, on the other hand, before moving the 'V' from the chosen ray, one arm looks blacker than the other, the patient's selection of the ray was evidently not perfect.

"The 'V' should always be *moved in the direction of its blackest arm* until agreement in the blackness of the two is arrived at. It will now be found to stand opposite the correct spoke of the fan.

"As in all tests of this kind, the patient's head should be held perfectly upright, and he should be made myopic for one of his two principal meridians; and emmetropic, or only faintly myopic, for the other. In other words, the case should be rendered by lenses one of simple myopic astigmatism.

"In most cases I find the 'V' test to be of surprising delicacy, though with slow-minded patients repetition is sometimes necessary until they have learned how to compare different depths of black in the two arms of the 'V.'

"One advantage of Snellen's fan is that it detects cases of irregular astigmatism. If one line be black, for example, its two neighbors faint, and the third or fourth black again, the case is proved to be one for which all lines and stripes are unsuitable, and the 'V' test should not be employed. For such cases test types only are permissible."

2 The Arrow Test

"This consists of a broad arrow bisecting a large cardboard disc; rotatable about its center, and with a square of stripes on each side of the arrow. A fixed graduated semicircle below, completes the apparatus. (See Fig. 2.)

"On turning the tail of the arrow in the direction of the 'cleanest' feather till the two feathers appear equally clean, the arrow-head points to the required axis. As a confirmation, the two edges of the arrow-head should then also appear equally matched, and the shaft of the arrow show its best definition. The axis being thus determined, to find the amount of astigmatism it only remains to direct attention to the squares, and insert minus cylinders in the trial frame till one is reached which equalizes the clearness of the two sets of stripes. A small minus sign on the edge of the cardboard disc, 90 degrees from the arrow-head, indicates the axis of this required minus cylinder. It is, of course, taken for granted that the eye is made faintly myopic for the

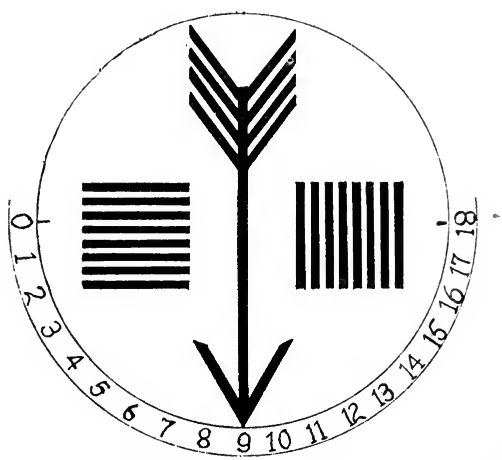

Fig. 2. The arrow test.

whole chart to begin with, and before inserting cylinders the correct spherical correction should be made for the best square."

For small children, however, such tests are too complicated. The writer advises dependence upon retinoscopy, but says that subjective confirmation may be obtained by the use of two squares, called pocket-handkerchiefs, one above the other and two striped circles, called balls, similarly placed.

(Excerpted from the *American Journal* of *Ophthalmology*, Vol. 4, p. 571-2, 1921.)

The Relationship Between Convergence and Accommodation

Harry M. Bestor, Opt. D.

BY way of introduction, it is simply necessary to say that tonic convergence is that amount of convergence necessary to bring the eyes from their anatomical state of divergency to parallelism; accommodative convergence is that amount of convergence which always accompanies accommodative activity; and fusional convergence is that supplementary amount of convergence which either adds to the tonic and accommodative convergence (*positive fusional convergence*) or subtracts from it (*negative fusional convergence*) in order that the visual axis may intersect at the point of fixation if tonic and accommodative convergence are deficient or excessive. (See Figures 1-A and 1-B.)

If it were not for tonic convergence our tonicity (phoria) tests would always show exophoria to the amount of our physiologic exophoria.

Tone of the interni, just as in tone of any other part of the muscular system, implies a subminimal contraction innervated by a subliminal innervation. Thus subminimal contraction, or tone, neutralizes the anatomical tendency

toward divergency of the visual axes and brings them to practical parallelism, in exactly the same manner and from exactly the same cause (subliminal innervation) as the

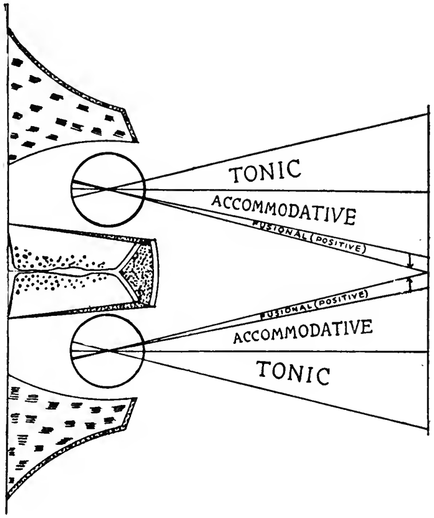

Fig. 1-A. Illustrating tonic, accommodative and positive fusional convergences.

ciliary is kept in a constant state of tonic contraction (tonic spasm) during a long period of years. Indeed as has been long taught by the writer and quite recently brought out by Dr. David Kletzky in the *American Journal of Physiological Optics*,* the relationship between accommodation and convergence begins with the absolute zero point of accommodation and the anatomical divergency of the visual axes. Technically this would qualify tonic convergency as a form of accommodative convergence just as latent hypermetropia is technically a form of facultative hypermetropia.

*The Starting Point of the Relationship Between Convergence and Accommodation—*American Journal of Physiological Optics*, Vol. 1, page 348, 1920.

If it were not for accommodative convergence binocular single vision would depend upon convergence as a separate function and there would not be the beautiful synchronization of the two functions. This condition is found

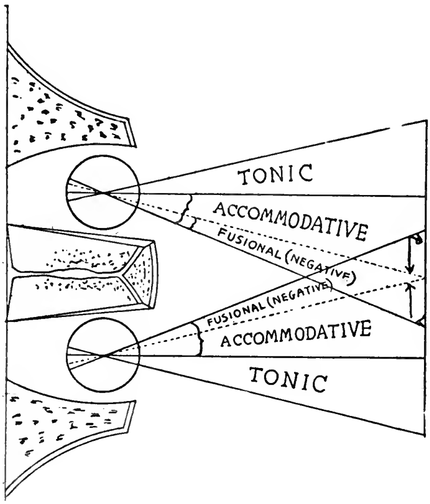

Fig. 1-B. Illustrating a condition in which negative fusional convergence is required.

absolute or in degree, in uncorrected myopia, with the result that these cases quite readily acquire exotropia; if not in distant use at least in near use of the eyes.

If it were not for fusional convergence all cases where tonic and accommodative convergence did not bring the visual axes to a point of intersection at the point of fixation would result in either homonymous or heteronymous diplopia and eventually esotropia or exotropia.

However, before attempting to present the writer's ideas about the relationship between accommodation and convergence it might be advisable to discuss some of the established ideas on the subject.

Quite commonly this relationship is given as a ratio of three to one: that is, that under ideal conditions, for every diopter of accommodation there are associated three prism

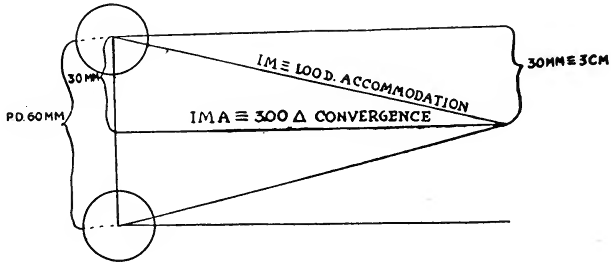

Fig. 2. Illustrating the application of the Prentice rule.

diopters of convergence. Calculations by the Prentice rule or by trigonometry show this relation to exist only in an orthophoric emmetrope with a P. D. of 60 mm. (See Figure 2.)

Because of the common third nerve innervation to accommodation and convergence it has been taught by many that when the eyes are accommodating for any given distance there should be just that proportionate quantity of convergence required for fusion of the macular images. According to such teachings, with fixation at one meter for example, in orthophoria-emmetropia there will be one diopter of accommodation and one meter angle of convergence.

Departure from this ideal is accounted for by relative accommodation and convergence. Thus, with the same fixation, a hypermetropia of one diopter would require two diopters of accommodation to one meter angle of convergence and a myopia of one diopter would require no accommodation and one meter angle of convergence. The former by positive relative accommodation accommodating in excess of convergence and the latter by positive relative convergence, converging in excess of accommodation.

Such teachings admit by inference the subdivisions of convergence suggested by Maddox but apparently are wrong in their assumption that tonic and accommodative convergence alone usually accomplish intersection of the visual axes at the point of fixation.

If the accommodation and convergence are dissociated by means of 4^{Δ} prisms, base up in one eye and down in the other, as described by Sheard in his *Dynamic Ocular Tests* and *Physiological Optics*, and investigations are carried out at the normal reading distance while the patient accommodates, experimentations by such authorities as Maddox, Howe, Sheard and others have led to the conclusion that there is a normal or physiologic exophoria at 33.3 cm., of approximately from 4^{Δ} to 6^{Δ}. It does not appear valid, therefore, to attribute the whole convergence necessary to binocular single vision to tonic and accommodative convergence alone but rather to tonic, accommodative and fusional convergence.

While the accommodation and convergence are thus intimately related and normally co-existent, yet the one can be made to *apparently* exceed the other. For any given distance we can reduce accommodation with convex lenses and increase its operation with concave lenses without producing double vision, thus proving that either convergence is unaffected by the altered accommodation or if it is, *is able to counteract such effect by some compensating agency.*

It is the writer's opinion that the latter is the true explanation. Again resorting to the prism dissociation test it is easily shown that reduction of accommodation by the addition of convex lenses results in a proportionate divergence of the visual axes while the increase by the addition of concave lenses results in a proportionate increase of convergence.

The Relationship Between Accommodation and Convergence

It would seem that investigation of these conditions should convince anyone that *every act* of accommodation results in

a proportionate act (true or suppressed) of convergence. Maddox seems to have been the first to arrive at this truth for his experiments led him to state that for every diopter of accommodation there is developed approximately ¾ of a meter angle of convergence. The researches of Howe and Sheard have corroborated this. However, they all admit this truth and then proceed to explain the non-ideal relations of accommodation and convergence by discussion of relative accommodation and convergence.

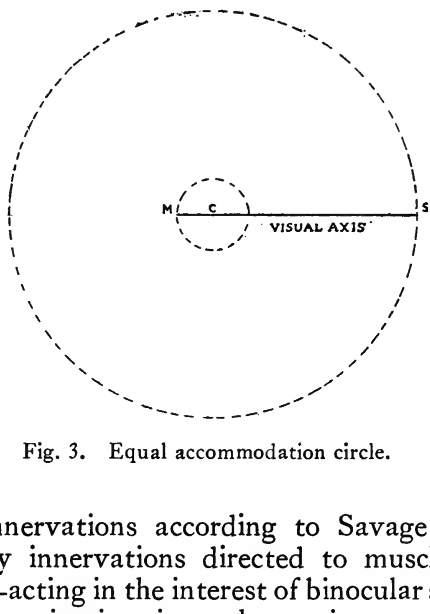

Fig. 3. Equal accommodation circle.

Fusional innervations according to Savage are always supplementary innervations directed to muscles that are over- or under-acting in the interest of binocular single vision. A little investigation into the various conditions encountered in binocular use of the eyes will show it is only in rare instances that the present methods of account for accommodative convergence relations will serve and how constantly some such explanation as fusional innervations offer is necessary to an understanding of binocular single vision.

If we consider the visual axis as a line, Figure 3, having

at one extremity the macula, M, and the other a special point, S, and revolve this line around a point upon it, C, corresponding to the centre of rotation of the eye, we will create two concentric circles, the eye and the spacial point, or equal accommodation circle. If we construct two such circles separated by a distance to represent the interpupillary distance, they will intersect at a point in front of the eyes which in ideal conditions will give us a point of equal accommodation and convergence. (See Figure 4.)

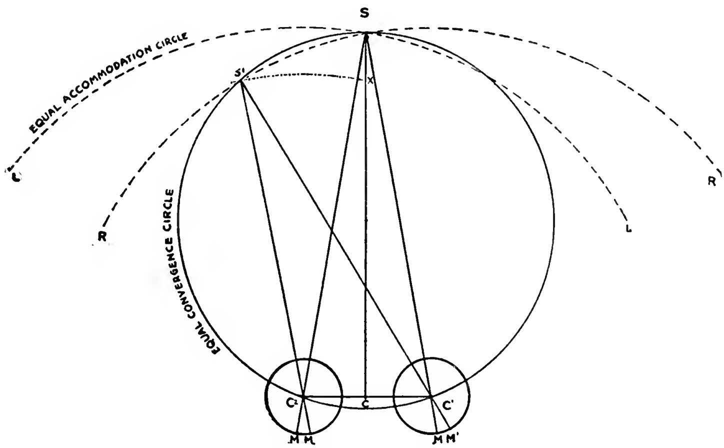

Fig. 4. Equal accommodation and convergence circles.

If around this point and the centres of rotation we circumscribe a circle we shall have the field of equal convergence, but the point of intersection, S, of the two monocular equal accommodation circles is the only point in the equal convergence field where equal accommodation for both eyes will pertain. If the eyes rotate to a secondary point of view, S^1, maintaining the same angle of convergence, by virtue of remaining in the circle of equal convergence, the right eye would fall within its equal accommodative field

but the left eye would fall within a concentric field represented by the arc, S^1X, and would require greater accommodation for distinct vision.

Maddox assumes that the centers of accommodation are so intimately associated that one does not normally accommodate more than the other under such conditions. He further contends, since accommodation with normal refraction implies positive effect, that the eye which is farthest from the object and can see it with least effort determines the accommodation for both.

Experience, however, would indicate that we undoubtedly do have fusional innervations to the ciliary as well as to the extrinsic muscles and it is not incompatible to accept the existence of such a condition and still hold to the theory that every time the eye accommodates it also converges in degree. In fact cases of marked anisometropia, where there is convergent strabismus because of uncorrected hypermetropia, show the strabismus in the more highly hypermetropic eye.

The intersection of the circles of equal accommodation and convergence will demonstrate:—

1 Equal accommodation and convergence for both eyes can only exist at one point, the point S, on the extended median line C. S. (Figure 4).

2 Equal accommodation for either eye (monocularly) exists at only one other point in the circle of equal convergence and that on the opposite side of the median line.

3 Were the relation between accommodation and convergence inflexibly equal there would be a diplopia for any object outside of the plane except possibly at one point on each side, within which diplopia would be heteronymous from relative divergence and without which diplopia would be homonymous from relative convergence.

4 The farther the point of fixation is moved from the median line the greater becomes the physiologic difficulty of converging the eyes so that the excess of convergence

effort required above the demands made upon accommodation efforts increases in proportion to the lateral deviation of the line of regard.

According to Maddox, with accommodation and convergence at 10 inches, this varies from 6° at the median line to 12° 36′ at 35° to either side.

Part of this great difference is probably due to the conflict between the innervations to the versions in right or left versions, as the case might be, and those to convergence.

A careful analysis of the conditions which this article has merely attempted to outline, would undoubtedly show the difficulty of explaining relationship so complex as those of accommodation and convergence by the handy agency of relative accommodation, but should show the logic of Maddox's discovery that whenever we accommodate we converge and that conditions arising from this which would interfere with binocular single vision are overcome through the agency of positive or negative fusional convergence.

(Taken from the *Archives of Optometry*, Vol. 1, pages 134-142, 1922.)

The Visibility Function and Visibility Thresholds for Color-Defectives

Margaret C. Shields

NO adequate efforts have been made to connect the type of color deficiency with the form of the luminosity curve. The writer, herself a deuteranope, has made some special investigations at the Nela Research Laboratory using a special equality-of-brightness spectrophotometer. This apparatus is primarily a Lummer-Brodhun spectrophotometer with collimators so arranged that brightness patches are made step by step through the spectrum for almost indistinguishable color differences. Watson (*Proceedings of the*

Royal Society, 88, p. 404) has presented the thesis that on the three process theory as represented by the Abney curves an observer, in proportion as he fails to get the green stimulus from white, should require more white to match in brightness a red than a normal observer, the effect being to shift his maximum visibility to red; conversely, an observer who loses relatively more red than green, should have his maximum visibility shifted to the green. The writer's case con-

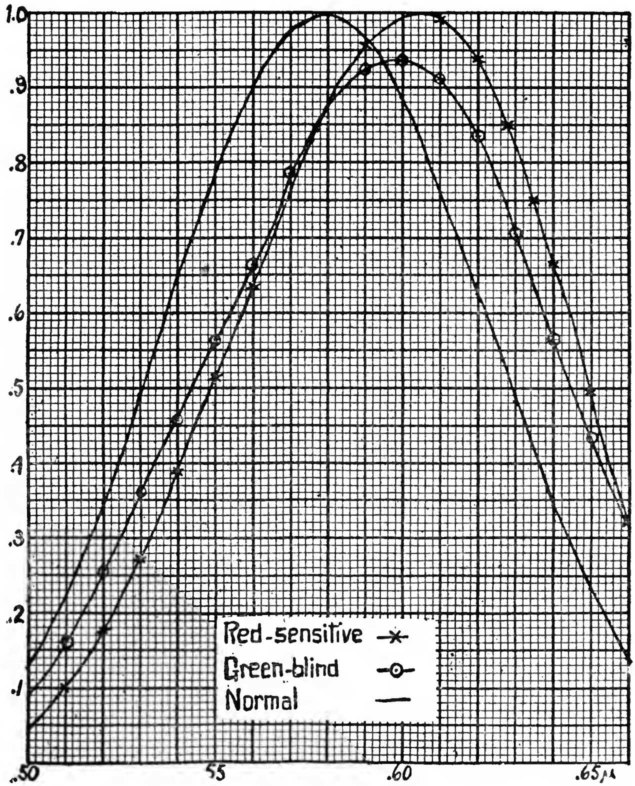

Fig. 1. Equal area luminosity curves.
(Source at 2045° K)

forms with Watson's theory, for she has no perception of green and sees the quality red except when the saturation is low. Her visibility curve has its maximum at 571 mμ as compared with 556 - 7 mμ for the normal eye. The writer also believes it more or less probable that relative blindness to red must somehow predicate a shift of the maximum visibility to the green.

The quantitative difference between the point of view of Watson and the measured cases shows that the totally green-blind should have their maximum definitely in the red, where the largest displacement found in one of Coblentz' cases is at 578 mμ. Also, contrary to the statement of Watson, the integral luminosity of the green-blind may be arbitrarily made equal to the normal without giving rise to an abnormally high maximum luminosity in the red (see Fig. 1).

In previous investigations measurements were made with the flicker method in which the observer measured the brightness in terms of white as he saw it, whereas the present results were obtained by an equality-of-brightness photometer using red at 650 mμ as a standard. Ives and others question whether the two methods measure the same thing. If color-blindness be rightly ascribed to a deficiency of the cones, and if in flicker methods the cones are relatively more important, the recognized divergence between the two methods might be found much more striking for color-defective eyes. But the two methods are in qualitative agreement.

On the basis of the simple three process theory which makes the total luminosity sense at each point in the spectrum the sum of the ordinates of three color sensation curves, Abney was led to draw curves giving for a person lacking the green sense as integral luminosity only 0.7 the normal and for a red-blind person only 0.3 the normal. This he justified on threshold measurements. Visibility thresholds were compared by the writer for a few cases of visibility functions of persons previously tested in the Nela

Laboratory with the one available color-blind case. The results are given for three typical cases in Fig. 3, showing in arbitrary units the minimum energy perceptible as a

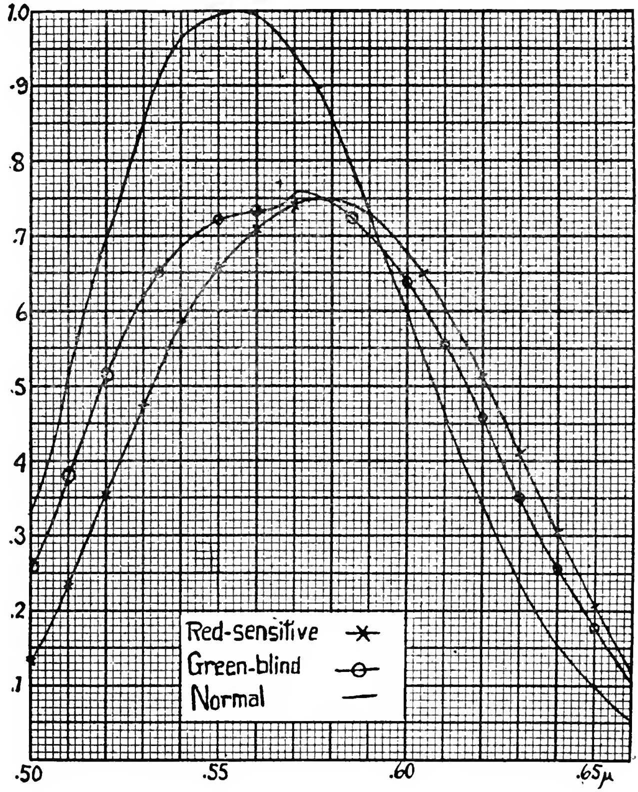

Fig. 2 Visibilityfunctions derived from the luminosity curves of Fig. 1.

function of wave-length; Fig. 4 shows the detail of the short wave-length portion of the same curves. The evidence is that there is no marked loss of brightness sensibility in the green color-blind case tested. The red sensitive subjects

of Figs. 1 and 2 with normal color vision have a somewhat lower threshold throughout.

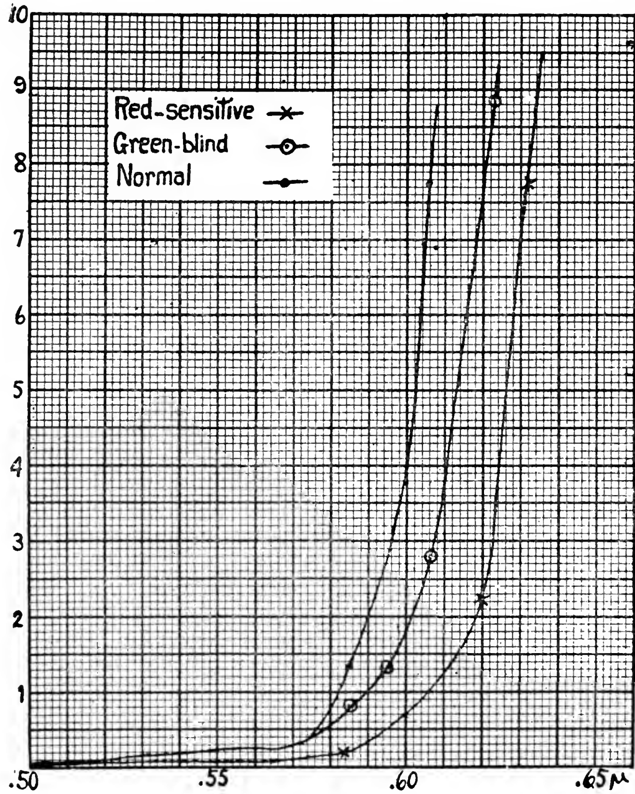

Fig. 3. Visibility thresholds.

The statement made by Tufts and by Coblentz is amply justified, that an abnormal visibility function is not necessarily associated with color-defective vision; but it is certainly equally true that there is no case on record of a color-defective with a normal visibility function. The existing evidence indicates, rather, that color-defective vision does

condition a perfectly definite modification of the visibility function; it would therefore appear that a theory of vision

Fig. 4. Detail of Fig. 3.

should interrelate brightness sense and color sense to the extent of accounting for this. It seems doubtful, however, if color-blindness does involve a lowered brightness sense in the extreme fashion in which the Young-Helmholtz theory has been interpreted to involve it.

(Abstracted from the *Journal of the Optical Society of America*, Vol. VI p. 362-8, 1922.)

Speed of Accommodation as a Practicable Test for Fliers

Major Lloyd E. Tefft, M. D., and Elizabeth K. Stark

THESE investigators have undertaken to ascertain the relationship, if any, of the speed of accommodation to other properties of the eyes, such as visual acuity as manifested by the ability to read Snellen type, depth perception as elucidated by the Howard-Dolman depth perception apparatus, the power of accommodation as determined with the Prince rule, the strength of the internal and external recti muscles as measured by the angle of convergence and as measured by the angle of convergence and the power of prism divergence and retinal sensitivity. These tests were made because it was believed that the speed of accommodation of the eyes possessed by a pilot played an important part in flying and especially in manoeuvres in which it might be necessary for a pilot to change his focus from far to near objects and *vice versa.**

The apparatus used was the tachistoscope developed by C. E. Ferree and Gertrude Rand of Bryn Mawr College.

It was so arranged that three test letters (two near, one at the left, the other at the right and one far in the middle) are exposed simultaneously to the observer and are then cut off from his view one at a time in a fixed order. "This is done by means of light-weight discs of variable open and closed sectors turned by means of a bar fastened at its center to the axle to which the discs are attached, and provided with adjustable weights on both arms." "The length

[*This same suggestion has come up with reference to the relationship between the speed of accommodation and automobile accidents, chiefly those in which moving pedestrians or suddenly moving objects close at hand are involved. Some have felt that the ease and quickness of ability to change focus from distance to near and *vice versa* exercised a considerable control over the nervous responses and muscular reactions existent in automobile driving. These experiments by Tefft and Stark indicate that this factor is of lesser significance than other defects. ED.]

of exposure can be varied either by changing the width of the open sector or the position of the weights on the arms."

The test letters used were the illiterate "E's," mounted so that they could be rotated to point in different directions. The working distance of the far test object was 6 meters and of the near test objects 30 cm.; the visual angles subtended in each case were 6′ 42″ and 0′ 10″. The brightness of the far test card was 10.40 candles per square foot; of the right and left test cards 1.68 and 1.16 candles per square foot respectively.

After a completed exposure, the subject was required to report the direction in which each of the "E's" was pointed. In order to perceive these successfully, he had first to focus on the near "E" at the left, then adjust for the far "E" in the center, and finally accommodate for the near "E" at the right. After a short practice period with slow speed, the exposure times for each letter were gradually shortened until the point was reached where the subject could just discriminate each. Then three correct judgments out of a possible five for a given setting of discs were required. The various exposures; near, near to far, near to far and back to near were recorded in terms of degrees of open sector and converted into time by a process of calibration. In working up the results, however, only the total time required for the complete excursion was used.

Without going into the details of the tests and of the data recorded, the writers believe that visual acuity, depth perception and extent of accommodation all show a moderate degree of correlation with speed, but with the omission of extreme cases the correlation between the visual acuity of the left eye and the speed of accommodation becomes the most significant. The power of prism divergence bears no relation at all to the speed of accommodation, and the correlation between retinal sensitiveness and speed is not high enough to be significant.

In the cases disqualified because of high refractive errors

there was a wide range of speed, one of them falling in the group of the best 15 percent of the cases. The few cases observed show no correspondence between decreased speed and extent of refractive error.

The paper closes with some conclusions of value with reference to the tests conducted and the selection of aviators. It is stated, however, that "those who possess a degree of speed of accommodation which might endanger their flying, possess other deficiencies which can be more easily detected."

(Abstracted from the *American Journal* of *Ophthalmology*, Vol. V, p. 339-342, 1922.)

Eyeglasses Versus Spectacles

Frank G. Murphy, M. D.

DR. GEO. M. GOULD'S article in *American Medicine* on eyestrain is in many respects timely. His warning that glasses should be kept polished, and that lenses prescribed for the relief of eyestrain should not be ordered in frames where there is danger that the lenses will not remain correctly placed, is logical. Indeed no competent oculist would prescribe eyeglasses for a patient whose occupation exposes him to strong currents of air, or for one whose nose is not properly shaped to hold them securely, no matter what his occupation might be.

However, his denunciation of all eyeglasses is too sweeping, for while there are many who, because of their vocation or shape of nose, should not wear them, there are thousands who can and do wear them and with greater comfort than spectacles. It is by no means true that spectacles always hold lenses before the eyes better than eyeglasses do. Let anyone for a day observe the disarranged eyeglasses and spectacles worn by those he chances to meet and it will be unusual if he does not see more spectacles with one glass cocked higher than the other, than eyeglasses improperly worn.

There are reasons why eyeglasses on many stay in place better than spectacles do. The frame of an eyeglass will give and become displaced on the nose when accidently struck, and is not as easily bent as the spectacle frame. Eyeglasses need only to be replaced on the nose but the adjustment of the bent spectacle frame is not so easily dealt with; and they may be worn for months with or without the patient's knowledge, and in any event the finding of an operator who will skillfully adjust them is a matter of more or less inconvenience. Any attempt the wearer may make to remedy his mishap will invariably result in its being made worse than before.

There are those who could wear eyeglasses as well as spectacles but because of their sensitiveness to the pressure on the sides of the nose, will not wear them, and a like condition is found among many who should wear spectacles. They are made so uncomfortable by the temples that hook over the ears that they refuse to be so annoyed when an eyeglass could be comfortably worn.

Eyeglasses are more easily put on and off than are spectacles, which is important to those who must remove their glasses frequently. From the former a chain may be attached to the clothing, but spectacles must be carried in a case, which is inconvenient, especially for women.

In this northern part of the country, during the winter months, the cold lenses immediately steam over when a warm room is entered, which necessitates their removal, and for this both hands are usually used, which also is a disadvantage. This occurs at a most inconvenient time and is particularly embarrassing to women who must disarrange their hair by the process. This trouble with spectacles would not be of great importance if this procedure were necessary to preserve the eyesight and health, and would be more gracefully endured if the sweeping condemnation of the eyeglass as made by Dr. Gould were justified.

The many eminent oculists who wear eyeglasses them-

selves and who prescribe them for their patients is evidence that they do not subscribe to the severe indictment of the eyeglass. Dr. Gould's high standing and long and useful service to the medical world gives importance to any words his hand may pen, though we presume he lays no claim to infallibility. It is my opinion that many will be unnecessarily inconvenienced by his expressed prejudice against the eyeglass, and that his opinion should not go unchallenged.

His criticism would be timely were we using the make of eyeglass frame manufactured fifteen and twenty years ago. But those in common use today are made with stiff guards which hold the lenses firmly in place and their use is of great comfort to thousands. Even the hoop spring is worn comfortably by many where spherical lenses are prescribed. The manufacturers of eyeglass mountings have for years been vying with one another to overcome all possible objections to them, and they have succeeded in a remarkable degree.

(Taken from the *American Journal of Ophthalmology*, Vol. 5, pages 360-1, 1922.)

247

The American Journal of Physiological Optics

Diffraction Halos in Normal and Glaucomatous Eyes*

H. H. Emsley, B. Sc. and E. F. Fincham

Synopsis

Every normal eye, under appropriate conditions, sees diffraction rings or halos encircling bright sources of light. Halos of a similar nature are seen by eyes in certain abnormal pathological conditions, particularly in the case of eyes suffering from glaucoma.

The practical importance of a more exact knowledge of the peculiarities of these halos was brought to the notice of one of the present writers at the instance of Lt.-Col. R. H. Elliot. The importance of the problem from the oculist's point of view rests upon the desirability of being able to differentiate with certainty between the halos seen by an eye in a normal condition and those seen by an eye suffering from glaucoma.

The present paper is an account of the results of some investigations into this problem carried out in the Applied Optics Department of the Northampton Polytechnic Institute, London.

I. Description of Coloured Halos

WHEN a bright source of light of small dimensions is observed in a dark room or in any place where there is a tolerably dark background, certain characteristic phenomena may be noted. In the first place there are circular, black diffraction rings immediately surrounding

*The manuscript and original drawings for this paper were transmitted to the *Editor* by Professor Emsley. Since the material therein contained was presented before the Optical Society of Great Britain, this article—according to custom—made its first appearance in print in the *Transactions of the Optical Society* (Vol. XXIII, p. 225-336, 1922). The discussion upon the paper is taken from the *Transactions* directly. The editor of this *Journal* expresses his indebtedness to both the authors and to those having in hand the publication of the *Transactions of the Optical Society*.

the source and caused presumably by diffraction at the border of the pupil of the eye. Secondly, the source is surrounded by an immense number of narrow streaks of light radiating out in all directions from the neighbourhood of the source as centre; this appearance has been called the ciliary corona. Its extent and appearance vary with the intensity of the source. The radiating streaks show the various spectrum colours, these colours being brighter and the rays of the corona longer the greater the intensity of the source.

The cause of the corona has been ascribed to the fibrous structure of the crystalline lens (Tscherning[1]), and to diffraction at the border of the pupil (Helmholtz[2]), while observations by Dr. C. V. Raman[3], who used both white and monochromatic light, lead him to suggest that the phenomenon is due to diffraction by minute particles in the humours of the eye.

Thirdly, the source is seen to be surrounded by a coloured ring (or, on occasion, rings), showing a gradation of colours from violet nearest the source to red outside, the more prominent colours being the green and red. If the source be sufficiently bright, the ciliary corona extends beyond this ring.

II. Historical

A. *Normal Eye Halos*

(1) The appearances have been recorded by various observers, *e.g.*, Tscherning, Sheard[4], Raman, Druault[5], Gullstrand[6]. There seems to be general agreement as to the appearance of the ciliary corona. With regard to the

[1] M. Tscherning, *Physiologic Optics*, 2nd edition (English translation), p. 157.

[2] v. Helmholtz, *Handb. d. Physiolog. Optik*, 3rd edition.

[3] C. V. Raman, *Phil. Mag.* (6), 38 (1919), 568.

[4] C. Sheard, *Amer. Journ. Ophth.* (3), 2 (March, 1919).

[5] A. Druault, see Morax, *Glaucome et Glaucomateux*, and Tscherning, *loc. cit.* p. 157.

[6] Gullstrand, see Helmholtz, *loc. cit.* vol. 1, p. 192.

coloured ring, also, most observers agree in stating the angular diameter of the yellow-green portion to be 6° or 7°.

A second, smaller ring of diameter about 3° for the blue has been described and called ring A by Tscherning; also Dr. Sheard gives the size of a second, but in this case, larger and fainter ring he has observed, as varying from about 8° for the violet to 16° for red.

In describing the appearance of a ring of 6° to 7° in diameter, Druault and Salomonson[7] state that it seems to appear to everyone when the pupil is dilated and that it is irregular and composed of radial striae. Gullstrand also observed that this ring appeared to consist of many small fragments not exactly similar and both he and Morax[8] have asserted that although many persons naturally have pupils large enough to see the rings without help, others require mydriatics.

(2) In the accounts given by the various writers quoted of the causes of the rings seen by normal eyes, it is agreed that they are due to diffraction by some fine structure present in the eye media. The rings are somewhat similar in appearance to (although less bright than) those seen when a light source is observed through a diffracting screen such as a glass plate covered with lycopodium powder or a spiral or radial diffraction grating. In all these cases the innermost of the coloured constituent rings consists of light of the smallest wave-length and the diameter of each coloured ring is approximately proportional to the wave-length corresponding to that colour.

The phenomenon has been attributed to the cells of the epithelial and endothelial layers of the cornea (Sheard) and to minute structures in the cornea or vitreous humour (Raman).

Druault observed a ring of somewhat the same size as the smaller ring of Tscherning, which he states was due to

[7] H. Salomonson, referred to in Tscherning and Morax.

[8] V. Morax, *Glaucome et Glaucomateux* (1921).

the endothelium layer of the cornea; but with regard to the 6° to 7° ring he, in agreement with Gullstrand, Koeppe, Tscherning and others, traces its cause to the fibrous structure of the crystalline lens.

In support of this latter explanation as to the origin of the 6° to 7° ring, Druault describes an experiment in which an opaque screen was moved in a horizontal direction across the observing eye. When the forward (straight) edge of the screen reached a position just beyond the centre of the pupil of the eye, the portions of the coloured ring round about the extremities of a horizontal diameter disappeared, leaving only the top and bottom quarters of the ring visible.

In this connection it is instructive also to note the remarks of Gullstrand. He states that on passing a small *aperture* slowly across in front of the eye in a radial direction, he observed that when the aperture was central with the pupil the ring disappeared completely, but on reaching the edge of the pupil two small spectra were seen, the line joining these two spectra being at right angles to the direction of movement of the aperture. From this he concluded that the diffraction phenomenon (of the 6° to 7° ring) was due to a radial grating in the neighbourhood of the edge of the pupil such as is present in the cortex of the lens.

Brewster[9], although he does not mention halos, refers to diffraction effects he observed by reflection from the surface of a crystalline lens and makes certain deductions from his measurements as to the size of the serrations of the edges of the crystalline lens fibres.

B. *Glaucoma Halos*

(1) Observations on the coloured halos seen by glaucomatous eyes appear to be less numerous. Gullstrand[10] states that they are larger in diameter than the normal eye ring. According to Tscherning, "the rings which glaucoma-

[9] A. Brewster, *A Treatise on Optics*, new edition (1831), p. 114.
[10] Gullstrand, *loc. cit.*

tous patients see resemble these rings (normal eye) but are generally larger (10° to 11°)." From observations made over a lengthy period up to quite a recent date R. H. Elliot[11] gives the size as varying between 6° 50′ and 11° 54′ and alludes to variations between one eye and another and with the same eye at different times.

Sheard states their size to be 10° to 12°; whereas Morax[12] gives the diameter as 4° to 5°, which is definitely smaller than the normal eye ring. There is thus a lack of agreement as to the size of the ring seen by a glaucomatous eye. The observations of Dr. L. Koeppe[13] are suggestive; he differentiates between a ring of diameter 3° to 3½° for red in glaucomatous corneal stasis without inflammation and "one of diameter 11° to 16° in the pre-glaucomatous and glaucomatous attacks of increased tension without any inflammatory signs."

(2) There is fairly general agreement in ascribing the cause of the glaucomatous halos to the formation of oedematous globules in the anterior layers of the cornea under the increased intra-ocular tension that accompanies the disease. Gullstrand and Morax describe the gradual decrease in intensity all over and the simultaneous disappearance of all portions of the halo, when an opaque screen is moved across the eye. The phenomenon is thus akin to that of the diffraction rings produced by a number of irregularly placed small circular obstacles or apertures, as in the case of a glass plate dusted over with lycopodium powder.

It is also stated that halos are seen by those aphakic eyes that become glaucomatous (Elliot), supporting the explanation that the cornea is the seat of the cause. The discrepancies between the sizes stated by different authorities may have some justification; it is permissible to suppose

[11] R. H. Elliot, *Glaucoma: A text book for students of Ophthalmology*, 2nd edition, Oxford Medical Pub. 1921. This work contains a good general account of glaucomatous halos.

[12] V. Morax, *loc. cit.*

[13] L. Koeppe, *Amer. Journ. Ophth.* (3), 4 (Sept. 1921).

that the sizes vary according to the stage of the disease (*vide* Koeppe above). A statement made by Tyndall[14] lends weight to this view. He states "One of the most interesting cases of diffraction by small particles that ever came before me was that of an artist whose vision was disturbed with vividly coloured circles. He was in great dread of losing his sight, assigning as a cause of his increased fear that the circles were becoming larger and the colours more vivid. I ascribed the colours to minute particles in the humours of the eye and ventured to encourage him by the assurance that the increase of size and vividness on the part of the circles indicated that the diffracting particles were becoming smaller, and that they might finally be altogether absorbed. The prediction was verified. It is needless to say one word on the necessity of optical knowledge in the case of the practical oculist."

III. Authors' Observations

As stated above, it is important for diagnostic purposes that the oculist be able to distinguish, with as much certainty as possible, between the coloured halos seen by a normal eye and those seen by a glaucomatous eye. Investigations have been carried out on both. Information regarding the latter can be obtained only from the person possessing the glaucomatous eye, and such cases, in this country at any rate, are not very numerous; moreover, the persons concerned are not skilled observers.

The results stated below with reference to normal eye halos are based principally on observations carried out by the authors themselves on their own eyes; the sizes of the rings, and their general character and behaviour, have, however, also been tested on numerous other eyes within the past few months, with similar results.

A. *Halos seen by the Normal Human Eye*

(1) The authors have not succeeded in observing more than one halo, except on rare occasions; in these cases the

[14] J. Tyndall, *Lectures on Light*, 2nd edition (1875), p. 92.

appearance of other rings was so fleeting that no definite remarks can be made upon them.

The one halo has been observed around various sources,

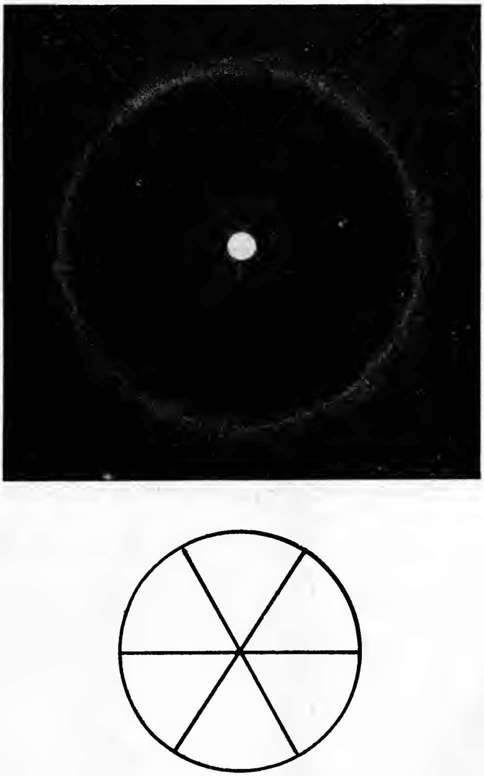

Fig. 1. Ring as seen by observer and the corresponding position of lens star.

such as the flame of an ordinary match or candle, the lamp of a luminous ophthalmoscope, an arc or "Pointolite" lamp behind a small aperture in an opaque screen. In all cases the surroundings were dark.

The intensity of the halo is very small in comparison with that of the source itself. (The intensity of the first of the series of diffraction rings caused by a circular obstacle, for example, is theoretically only $^1/_{57}$ of the intensity of the source itself.) Increasing the brightness of the latter, how-

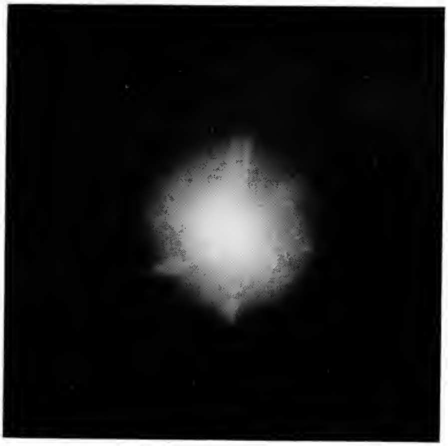

Fig. 2. Diffraction pattern of crystalline lens of sheep's eye.

ever, brings the ciliary corona so much in evidence that a point is reached when the halo is too faint in comparison to be seen. Even under the conditions found to be most favourable, the halo, in the authors' experience, is located only with careful attention, more especially when it is looked for deliberately with the intention of making measurements or other tests on it. Moreover, it is not always seen equally clearly by the same observer on different occasions, even when the surrounding circumstances are the same. It may be that this is due to variable physiological conditions; but it has been noticed that the pupil is usually small, perhaps after a tiring day, when the greatest difficulty is experienced.

Given good conditions, the ring is observed to be not exactly circular, nor of equal brilliancy at all portions. Six equi-distant portions, each of angular extent of roughly 20°, stand out somewhat more clearly than the remainder. Fig. 1 shows (not in colours, unfortunately) the ring seen by the left eye of E. F. F. on 3. xii. 21 and the corresponding position of the lens star of that eye, as found by placing near its anterior focal plane a minute source of light and so throwing upon the retina a shadow of the entoptic structures.

Fig. 2 is reproduced from the diffraction pattern produced by the crystalline lens of a sheep and photographed (12. x. 21); only the six portions of the halo are visible in this case.

These observations appear to suggest the possibility of the halo having some connection with the crystalline lens structure.

(2) *The size of the halo seen by the normal human eye.* The size of the halo was measured in a manner similar to that used by Young in his eriometer. The source, a 100 c.p. "Pointolite" lamp, was placed immediately behind a metal plate with a hole of 3 mm. diameter; at the extremities of a diameter of a circle of radius 2 cm., described around this hole as centre, were two further holes of 1 mm. diameter. By varying the distance of the eye from this plate, the two smaller holes can be made to coincide with any desired colour of the halo seen around the central hole. The lamp was enclosed to prevent illumination of the surroundings. In some cases this plate was fixed in the end of a postal tube within which telescoped a second tube, both blackened internally. In spite of the blackening, however, internal reflection was troublesome and subsequent observations were made in a dark room with nothing between the plate and the eye.

The results for the yellow-green constituent ring of the halo, from a number of readings with four different observers, are given in Table I.

TABLE I

Halo—Normal Human Eye. Size for Yellow-green

Observer	Angular diameter	Mean	Greatest spread
H. H. E.	6° 18′	6° 7′	22′
F. G. W.	6° 4′		
E. F. F.	6° 10′		
W. H. A. F.	5° 56′		

The authors made observations on quasi-monochromatic light by passing the light from a "Pointolite" lamp through a carbon disulphide prism and placing the centre of the eriometer plate in different portions of the spectrum successively. The results of these observations are set down in Table II.

TABLE II

Normal Human Eye. Size and Colour

Colour	Angular Diameter
Violet	4° 30′
Blue	5°
Green	5° 26′
Yellow	6°

The relation between the size of ring and wave-length of light forming that ring could be obtained somewhat more accurately by using monochromatic sources; but the ring observed is not clearly outlined and has an appreciable thickness, so that in any case the observer is called upon to estimate the mean position of the ring.

(3) *Effect of size of pupil.* The average size of the pupil in the above experiments was from 3 to 5 mm. diameter.

With an aperture less than 3 mm. diameter placed before the eye, the halo was not seen. The light entering the eye, it may be observed, covers in these circumstances a circle of about 2.5 mm. diameter on the crystalline lens.

The effect of dilating the pupil by cocaine to 9 mm. diameter was greatly to increase the intensity of the coloured rings and so to diminish the relative effect of the ciliary corona. No other effects were noted.

(4) *Animal eyes.* A fresh bullock's eye, with a portion removed from the posterior, was mounted in a small glass dish with the axis vertical in such a way that the media were kept up in position relative to the cornea and the latter as nearly as possible at its natural convexity; a diffraction halo similar to the one seen by a human eye was found on a screen placed at an equivalent distance from the cornea of 35 mm.; the angular diameter of this ring was roughly 18° for the blue and 27° for the red.

This experiment was repeated with a fresh sheep's eye; the size in this case was roughly 12.5° for the red.

In the experiment on the bullock's eye the halo was not at all well defined, so that too much reliance cannot be placed on the figures for this eye.

The authors have produced the halo also by means of the crystalline lenses only of sheep and bullocks. In these

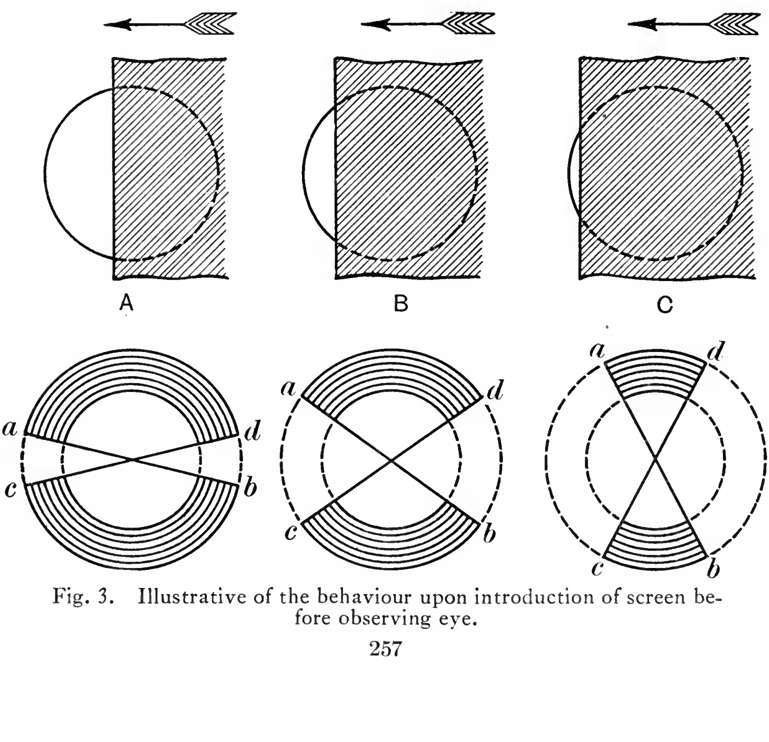

Fig. 3. Illustrative of the behaviour upon introduction of screen before observing eye.

cases the appearance was not a continuous circular halo; only six equi-distant portions of the spectral ring were visible. The effect is comparable with that of the human eye, the halo of which has six portions standing out more distinctly than the remainder, as stated above (see Fig. 2).

(5) *Behaviour upon introducing a screen before the observing eye or grating.* Upon passing an opaque screen with a vertical straight edge horizontally before the eye, the phenomenon described by Druault was observed; namely, that when the forward edge of the screen reached a position a little beyond the center of the pupil, the horizontal portions of the halo disappeared, leaving only the top and bottom portions.

Fig. 3 will assist in explaining this phenomenon. *A* indicates the appearance of the ring when rather more than half the pupil is occluded. In *B* less of the pupil is exposed and the missing portions of the ring *ac* and *db* have increased. *C* shows the screen exposing only the extreme edge of the pupil, in which case only the vertical extremities of the halo *ad* and *cb* remain.

The results tend to the conclusion that the halo is due to a structure that is of a more or less radial disposition, as in Fig. 4. For it will be readily seen, by passing a screen horizontally across the radial diagram (Fig. 4) that until more than half of the diagram is covered, radii in every direction are exposed so that the ring spectrum formed by a diffraction grating of this nature would not be affected, except in intensity. As soon, however, as the screen has passed the central position, we observe that the grating is deficient in vertical lines and therefore would produce no dispersion in the horizontal meridian; the appearance being as at *A* (Fig. 3).

As the screen is moved beyond this point, more and more of the lines are cut out until in the position shown at *C* only those lines approximating to the horizontal remain, producing two small arcs of spectrum in the vertical meridian.

Closer observation, however, revealed more than this;

it was noticed that the two edges of a dark sector appearing in the ring were not equally well defined, and that whilst with some eyes the line *ab* rotating in a clockwise direction

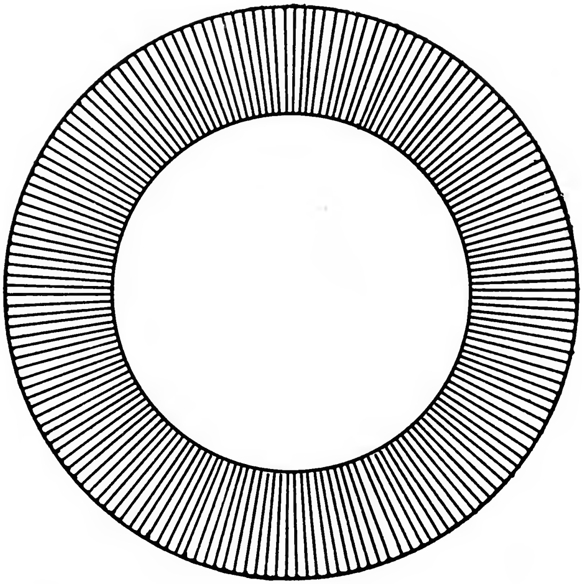

Fig. 4. Illustrating the radial character of the halo.

was the clearer, in others it was found that the line *cd* was the more distinct.

(6) Since this behaviour is quite different from that of the glaucomatous halo, and therefore is an important deciding factor as to whether an observed halo is normal or glaucomatous, further experiments were made.

A parallel-sided slit, 1 mm. wide (stenopaic slit), was passed before the eye. Preliminary observations confirmed that something of the same nature was happening. Closer attention revealed further detail.

Fig. 5 shows successive positions of the slit in front of the

pupil with the corresponding appearances of the halo. In *A*, when only a portion at the border of the pupil was exposed,

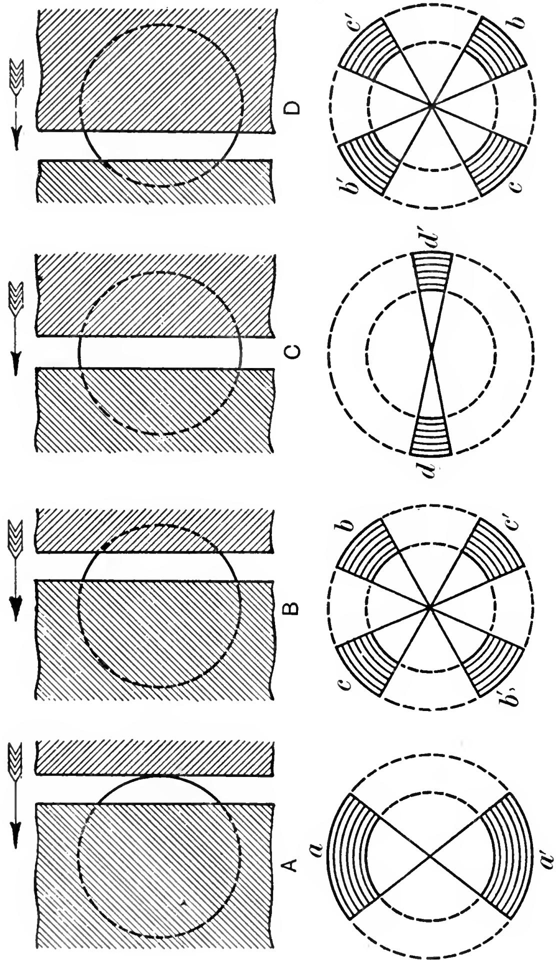

Fig. 5. Illustrative of the behaviour upon the passage of a stenopaic slit before the eye.

two portions *a*, *a'* of the halo were visible; upon moving the slit in a horizontal direction towards the centre of the pupil

to the position indicated in B, the portions a, a' appear to divide, forming b, c and b', c'. These portions rotated, b, b' in a clockwise direction and c, c' anti-clockwise, as the slit was moved still further. With the slit central, as in C, the portions appeared to reunite into d, d'. Upon continuing the motion of the slit, d, d' appeared to divide into portions b', c and c', b, the rotation continuing as before until finally these latter amalgamated as at a, a' in A, when the slit was at the other extreme position.

These are the results that would be expected from a radial structure. If a narrow slit be passed across the diagram in Fig. 4 it will be seen that the portions successively exposed are such as would produce spectra in the positions indicated in Fig. 5.

(7) It was further noticed that of the four portions, one pair, either b, b' or c, c', was constantly more distinct than the other pair, for a given eye. The pair pronounced to be the more distinct by one eye was not necessarily so for another eye.

The experiments were repeated, with the slit horizontal and moved in a vertical direction, with similar results.

These results are collected together in Table III. The directions in columns 3 and 4 are the directions in which the more distinct pair of spectra moved (C = clockwise, A = anti-clockwise).

TABLE III

Observer	Eye	Slit vertical moved horizontally ←	Slit horizontal moved vertically ↓
E. F. F.	R	C	A
	L	C	C
H. H. E.	R	A	A
	L	C	C
F. G. W.	R	A	C
	L	C	A

It thus appears that the halo seen by the normal eye is due to a structure which is, or has the property of, a radial

structure, extending to within a millimetre or so of its centre. Moreover, the last series of experiments indicates that the fibres are more in evidence at some portions of the periphery than at others. The fact that one of the two pairs of the spectra is brighter than the other would be accounted for if the structure were not equally perfect all round

The same results would follow too, if the pupil that is admitting the light to the system of the eye were displaced perpendicularly to the common axis relatively to the radiating structure.

If, for example, the entrance pupil E is displaced relatively to the diffracting structure A, as in Fig. 6, then the one pair

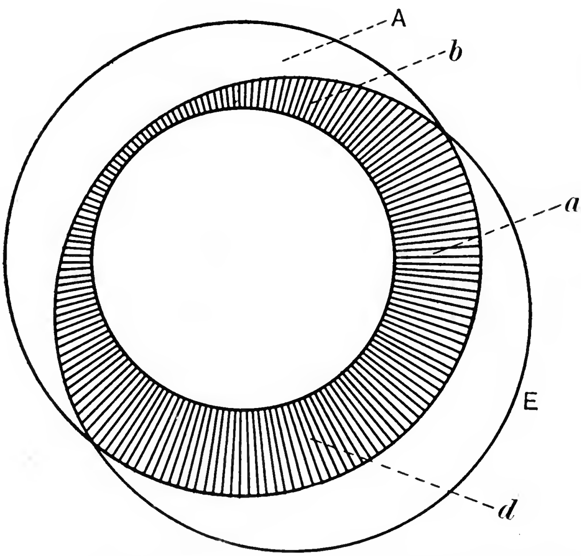

Fig. 6. Illustrative of effect of displacement of pupil with reference to diffracting structure upon spectra.

of spectra at the top and bottom, due to the fibres in the neighbourhood of a, would divide into two pairs when the

slit reached such a position as to expose fibres in the neighbourhood of *b* and *d;* and of these two pairs, the one due to the fibres at *d* would be brighter than that due to the fibres at *b*. As the slit was moved across in a horizontal direction from right to left, the brighter pair would rotate in a clockwise direction.

The known arbitrary relative displacement of crystalline lens and pupil would appear to be connected with this phenomenon; such investigations as the authors carried out did not, however, establish definite conclusions on this point.

Bearing in mind that, at least under the conditions used by the authors, the complete halo was not visible in the case of the crystalline lenses of sheep and bullocks, the behaviour under the slit test was of the same order. When the slit (vertical) occupied the peripheral position in front of the crystalline lens, of the six small spectra those portions at the extremities of the vertical diameter alone remained. With the slit central, only the horizontal portions remained.

B. *Halos seen by Glaucomatous Eye*

(1) The source of light used was a 20 watt frosted metal filament lamp, placed behind a small aperture of 5 mm. diameter in a screen in a dark room at a distance of about 2 metres from the patient. In each of the cases tested, one of the several symptoms complained of was the presence of "coloured rings round lights." These are not always seen, but only just before or during the attack, which may last for a period of several hours. During the period when the halos were in evidence, the ocular tension was found to be high, and the cornea had a slightly misty appearance. Other symptoms, such as severe headaches, etc., are not of primary importance to this investigation.

The intensity of the halos varied to some extent on different occasions with the same patient, but at the height of the attack they always were of far greater brightness than those seen by the normal eye. The ciliary corona was

scarcely visible, the space between the source and the blue ring being dark grey, scarcely distinguishable from the blue, which one patient described as royal blue. The ciliary corona, however, became much more evident when a more intense source was used.

(2) The angular diameter of the halo was measured in substantially the same manner as the normal eye halo above. A small, not very bright, electric lamp was moved in front of the screen radially towards the source until it coincided, first with the outermost (orange) constituent ring seen by the patient and then by each coloured portion of the ring in turn.

The average of a number of such measurements is given in Table IV; the table gives the angular diameter in degrees.

TABLE IV

Colour	Patient *A*	Patient *B*
Blue	4°	4 to 5°
Green	5° 26′	6°
Yellow	6° 18′	6° 54′
Orange	7° 26′	8°
Orange-red	9° 26′ extreme edge	8° 36′

The measurements appear to indicate that there is a small difference in size of the halos as seen by different eyes; a difference which, though small, cannot be neglected. Moreover, there were indications that the size of the ring varies at different times with the same patient.

(3) Upon passing an opaque screen in front of the eye, the ring was stated by the patient to decrease in brilliancy and finally disappear, all portions of the ring disappearing simultaneously.

On one occasion a second halo, concentric with the first, was stated to be visible, but was too faint for measurements of its size to be made. This patient stated that on occasions three concentric halos are visible.

IV. Conclusions

Although this interesting problem has not by any means

been exhaustively treated here, certain conclusions, of practical use to the oculist, emerge.

A. *Normal Eye Halos*

The halo, except on rare occasions when all circumstances as to brightness of source, surrounding darkness, etc., are favourable, is seen only with difficulty and with previous knowledge as to its existence.

The size is approximately constant in all normal eyes at rather more than 6° angular diameter for the yellow ring.

The results of the observations indicate the crystalline lens as being the cause. When an opaque screen or slit is moved across the observing eye, only portions of the halo disappear, the remaining portions moving round the circle as the screen or slit exposes different portions of the pupil.

B. *Glaucomatous Halos*

The halo, when seen, varies in brightness at different periods of the attacks but is always appreciably more vivid, and usually far more so, than the normal eye halo.

The size also appears to vary at different stages of the disease, so that size alone cannot be accepted as a criterion of the differentiation between glaucomatous and normal halos.

When an opaque screen is moved across the eye the halo behaves as those formed by a number of equal small particles; that is, the halo gradually decreases in intensity and finally disappears simultaneously all over. Evidence points to the cause being a formation of oedematous globules in the tissues of the cornea due to the increased intra-ocular tension.

It thus appears that there are definite differences between the glaucomatous halo and the normal eye halo: firstly, the glaucoma halo is much brighter than the normal eye halo; secondly, the "slit test" produces different phenomena in the two cases.

Much interesting information with regard to the structure

of the eye and these entoptic phenomena could doubtless be obtained from further research on these lines. Experiments are in progress and, it is hoped, will form matter for a subsequent paper.

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DISCUSSION

Lt.-Col. R. H. Elliot (communicated): It has long been well known that an eye suffering from the disease known as glaucoma is liable to see coloured halos around lights, and that these halos are diffraction phenomena. It is less well known that coloured rings, which may be mistaken for those which occur in glaucoma, may be seen under a variety of conditions by quite normal eyes, and that anything which dilates the pupil of the eye makes it easier for such rings to be seen. The phenomena of "rainbows round lights" is well known to glaucomatous patients, and through them to a large section of the public. Moreover it is a very arresting symptom, and one which is not only easily observed but which at night time forces itself upon the attention and is apt to give rise not unjustly to feelings of serious alarm.

It must be obvious from these considerations that it is a matter of great importance to ophthalmic surgeons to be able to distinguish clearly between what are sometimes called "the true halos of glaucoma" and physiological halos. It is true that no surgeon should or would operate on the strength of one sign alone; he would take the whole case in its entirety, but all the same he might be strongly prejudiced by so outstanding a phenomenon as this undoubtedly is. It would be no small misfortune if he were induced to undertake an operation, or even to place a patient on a prolonged course

of treatment for glaucoma, when the disease is not actually present. There is yet another point. As surgeons we often have to use drops which dilate the pupil, and not a few people will see distinct halos under such conditions. I have already said that the public are familiar with halos as a sign of glaucoma. Many of them also know that an attack of glaucoma may be precipitated by the artificial dilatation of the pupil as a result of the use of drugs. You will see from all this how essential it is that we should be able to distinguish clearly between the true halos of glaucoma and those which imitate them.

I have for a long time been interested in this subject, and through the courtesy of Mr. Beck I came to know of Mr. Emsley, to whom I put my difficulties. He and Mr. Fincham, working together, have devised a test whereby the true halos of glaucoma and the false or physiological ones can be easily distinguished. Their test turns on a very simple physical fact, viz., that the glaucoma halos are due to diffraction of the light by globules of fluid which collect in a portion of the cornea or clear window of the eye as a result of the obstruction to the circulation in this membrane caused by glaucoma. The physiological halos, on the other hand, have been shown by their phenomena to be due to diffraction at a radial grating. It has long been known anatomically that the arrangement of the fibres in the lens of the eye is such as to constitute this structure a radial grating. Fortunately for us diffraction at this radial grating is not a very active phenomenon in the majority of people though it apparently becomes more active as life advances. There is also strong reason to believe that the peripheral parts of the lens constitute a much more active diffracting medium than the central part. As is well known, the pupils contract in a bright light, and in doing so cut off the lens periphery and so save us from unpleasant diffraction phenomena. If, however, the pupil is naturally widely dilated, or is so dilated by the use of drugs, or if again, a portion

of the iris of the eye has been removed, thus exposing the periphery of the lens, the physiological halos may become much more pronounced and lead to unpleasant symptoms, and so to deep anxiety on the part of the patient and even of the surgeon.

So little has been known on this subject that I feel that we are under a great debt to Messrs. Emsley and Fincham for having devised a test whereby we can so accurately distinguish between the true halos of glaucoma and those which imitate them.

One last word—the true halos of glaucoma vary widely in diameter. I have measured a number of them, and have found that the angular measurements of these rings may vary from under 7° up to nearly 12° and that they may vary in the same patient from time to time. This is undoubtedly due to corresponding variations in the diameters of the tiny fluid particles which give rise to the diffraction phenomena. It is probable that at an early stage the fluid particles would be small, and the rings consequently large; at a later and acute stage the fluid particles would be at their largest and the rings therefore at their smallest; lastly, as the disease is passing off the fluid particles would again become small and the rings would increase in diameter. On the other hand, the physiological rings, which are the result of diffraction by the fibres of the lens, are constant in size (7° to the outer orange red ring), for the simple reason that, within certain margins, the lens fibres are constant in diameter. This furnishes another easy and satisfactory test in many cases.

Dr. E. Claude Taylor said that the new tests suggested by the authors were proving very valuable. He mentioned the case of a patient of his who, subsequent to a successful operation for glaucoma, was very much worried because the halos persisted; the surgeon was led to think that a further operation might become necessary. The authors had applied their tests and found that the patient described

the phenomena exactly on the lines of the lens diffraction halos, there being no actual condition of glaucoma present.

Lt.-Col. H. Kirkpatrick stated that halos were an undoubted source of annoyance to patients. He had personally experienced them on one occasion when his pupils had been artificially dilated. He drew attention to causes of the appearance of halos other than glaucoma and lenticular diffraction. A thin film of blood, spread over the surface of the cornea by the movements of the lid, may cause the phenomenon owing to diffraction by the blood corpuscles; this may occur in India where chicken's blood is sometimes used by quacks as an application to the eye on account of its supposed "cooling" property. Muco-purulent discharges may act in the same way, and halos have been observed to follow the application of caustics, such as nitrate of silver, to the conjunctiva; in such a case some of the fluid may reach the corneal epithelium and, by causing degenerative changes in it, lead to diffraction.

Dr. M. Dobson drew attention to a number of other conditions of the eye which give rise to halos.

Dr. E. E. Maddox (communicated): The authors have proved their points very lucidly. Those of us who are engaged in the multitude of subjects which comprise ophthalmology have little time for the uninterrupted study of pure science and it seems a capital idea for the Northampton Institute to be utilized for such work.

The optical packing between the lens fibres is evidently more perfect in the central portions of the lens, and Nature has not been so careful about it near the periphery, for in ordinary life the pupil contracts sufficiently when a strong light is looked at. In the human body provision is never made when no need for it exists. The diagrams prove the radial fibrillation of the lens beautifully, and it is quite beyond doubt that physiological halos are lenticular.

I look on glaucomatous halos as due to *subepithelial sweating of the cornea*, raising the epithelium into multitudes of

tiny hillocks, rather than oedematous globules in the proper substance of the cornea, which latter would not, I think, have the effect. Stretching of the cornea might conceivably contribute also by dislocating the fibres from their optical packing and, since they run in all directions, the phenomena produced by a screen passing across the cornea would differ entirely from the lenticular ones and resemble those so well known in glaucoma.

Prof. Cheshire said that the diffraction phenomena which the authors had described agreed in every detail with the experiences of those who had examined such phenomena in microscopy.

Mr. W. H. A. Fincham: It may be of interest from a historical point of view to notice that Descartes in his *Discours de la Méthode*, dated 1637, gives an account of the coloured coronas seen around flames and lamps, and shows that they are produced, not by the air, but by the eye which sees them. He describes how after resting at night with his right eye upon his hand, when a lighted candle was brought to him, he saw with his right eye the coronas *AB* and *CD* around the flame, as depicted in the figure photographed from his book. "Their colours," he says, "were

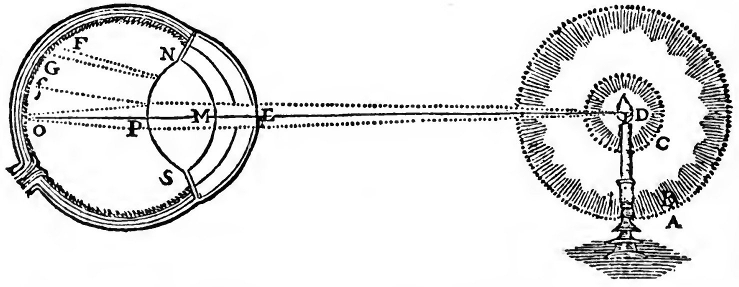

Fig. 7. Illustrating Descartes' view (*Discours et la Méthode*, 1637).

as bright as I have ever seen them in the rainbow." Descartes' attempt to explain the phenomenon is not very enlightening, except that he realized that his eye had acquired some

altered disposition whilst he pressed upon it. He suggests that one or two circular wrinkles may have been formed in the surfaces of the eye marked *E*, *M*, *P*, or again that the humours or membrane of the eye have in some manner changed in constitution or shape; "for," he says, "it is common to those who have diseased eyes to see such coronas, and they do not appear similar in all cases."

Mr. C. L. Redding: The difficulty in seeing the physiological halo is largely due to the smallness of the pupil. Although the pupil of my own eye is small I can see a distinct break in the halo on passing a slit in front of the eye, provided the latter has been dark adapted for about five minutes. There is no reason why opticians should not apply the straight edge and slit tests in the case of patients who are suspected of having glaucoma. It is desirable that ophthalmic surgeons and opticians should co-operate more closely and discuss problems of mutual interest.

Authors' reply (communicated): The kind of halos referred to by Lt.-Col. H. Kirkpatrick and Dr. M. Dobson are well known. They are caused by the formation in some manner, either natural or artificial, of a broken film on the outer surface of the cornea. The halos thus disappear when this external film is removed (which can usually be done in a moment), indicating at once that they are not due to glaucoma or to the crystalline lens.

The authors have carried out tests on such halos by introducing a drop of blood into the conjunctival sac, the resulting halos being marked but not of any special significance. For a period during the summer of 1921 one of the authors could see a halo each morning, due to mucus having formed on the cornea; it became broken up at the first blink or so of the eyelids. The opportunity was taken of roughly measuring the size of this halo which was found to have an angular diameter of 14° for the red ring.

The paper was intended to show the difference between

the normal or physiological halos and those due to glaucoma; these are caused by structures *inside* the eye.

Dr. Maddox's view of the cause of glaucomatous halos, namely, as being due to the raising of the epithelium into tiny hillocks by the subepithelial sweating of the cornea, is very interesting. The fact of this being the case would not, as he points out, affect the fundamental difference between the two classes of halo that are the subject of the paper. The authors assumed, without making any investigation on the point, the correctness of the generally accepted view that glaucoma halos are due to the oedematous globules themselves. The authors are pleased to have called forth this view of Dr. Maddox's and think that probably it is worthy of investigation.

The Nature of Light

Prof. Max Planck

being a

Translation of a Lecture Printed in

Deutsche Optische Wochenschrift

by

Otto G. Haussmann

THE very first problem which confronts us in the study of physiological optics, in fact the preliminary consideration which makes possible a purely physical theory of light, is the subdivision of the entire complex of phenomena dealing with the perception of light into an objective and subjective part. The first, or objective part, comprises the action of light as it takes its course outside and independently of the sensitive organ — the living eye — and deals with what has been termed the light rays, which constitute the domain of physical optics and research. The second, or subjective part, takes into consideration the course of the light-rays as they enter the eye and pass into the brain, the study of which leads us into the realm of physiology and even psychology.

It is not to be assumed that a distinct separation of the objective light-rays from the physiologic perception of light can be readily accomplished. On the contrary, such a division involves an arduous mental analysis and requires considerable concentration. As late as a hundred years ago the German poet Goethe, who was endowed with a philosophical mind and possessed a vast knowledge of all the natural sciences, although not much given to analytical contemplations, asserted that he never saw the part without seeing its entirety; throughout his entire life he refused to admit the possibility of a separation of the physical light

from its physiological perception. In fact, what could be more self-evident to a layman than a bare statement to the effect that light, without a sensitive, perceiving eye is inconceivable and therefore nonsensical?

But what is meant by the word "light" as used in the foregoing sentence, with a view to giving it an unimpeachable import, is something entirely different from the light rays which concern the physicist; and even though the word "light" is retained for the sake of convenience, the physical science of light or physical optics, in its full meaning as generally accepted, has no more direct connection with the human eye and its perceptive power than the problems of pendulum oscillations have with the perception of sound-waves.

The discovery that light requires a measurable length of time to travel was of decided importance in the investigation of the physical nature of light. This is true of light which has as its source a luminary body as well as that which is produced artificially. But what is this something which travels through space in all directions with the enormous velocity of 186,000 miles per second?

Sir Isaac Newton, the founder of classical mechanics, held the simplest and most obvious view, that light consisted in the propagation of certain minute but substantial particles which emanated from a source of light, such as a red-hot body, and travelled away from the source with a tremendous velocity in all directions, and which differed in kind for each color; and, even in our own days, it is a particularly significant proof of the fact that in the most exact of all sciences a recognized authority may, under certain conditions, wield a retarding influence on the development of a science, especially when we consider that for an entire century the emission theory of light, as proposed by Newton, remained firmly entrenched even though it was, from the very beginning, opposed by another eminent scientific investigator, Christian Huygens, who upheld the much more plausible and consistent undulatory theory of light.

Huygens illustrated the velocity of light, not like Newton, by drawing a parallel with the velocity of the wind but by representing the velocity of light as being analogous to the velocity of the sound-waves; the latter, as is well known, depend for their velocity on something very different from the mere movement of the air currents.

A further essentially important and significant step forward in the investigation of the nature of light was made when the identity of light-waves and heat-waves was established. This discovery indicated the first step toward a complete severance of the physical light-waves from their physiological perception. It is not at all surprising that an assertion to the effect that, barring the marked difference in wave-length, the cold light-rays of the moon, physically considered, are of precisely the same nature as the dark heat-rays of a heat-generating stove, should have been received at first with a great deal of skepticism. It is significant, too, that the physicist Melloni, who took the most prominent part in the verification of this assertion, originally made his experiments with the intention of disproving its correctness.

The confirmation of the relationship between the light-emitting and heat-producing infra-red rays made it a comparatively easy task to also establish their relationship with the chemically active ultra-violet rays contained at the other end of the spectrum; not until years afterwards, however, was it discovered that it was quite possible to extend, toward both extremes of the spectrum, the connection between the various rays.

Not only Newton and Huygens, but also their immediate successors, in spite of all the differences in their views, were one in the opinion that the investigation into the nature of light must be carried on in the domain of mechanical science. It was in the middle of the 19th century that James Clerk Maxwell proposed the audacious hypothesis that light is an electro-magnetic phenomenon.

Through his theory of electricity (which first appeared in his *Treatise on Electricity and Magnetism*) he came to the conclusion that the velocity of light in vacuo must be numerically the same as the ratio of magnetic units, *viz.* 186,000 miles per second. The coincidence of the velocity of light with the velocity of electricity, the latter being determined by him by electric measurements, first led him to advance the theory that light was nothing more or less than an electric disturbance. Here, too, the only proof of the tenableness of the theory is the fact that experience, so far, has demonstrated that all the deductions drawn from it are capable of verification.

Of course, the nature of the electro-magnetic phenomena is no more subject to an intelligent explanation than that of the optical. He who would, however, consider the advancement of the electro-magnetic theory of light as a disadvantage for the reason that it only substitutes one riddling line of reasoning for another does not realize the importance and significance of this theory; for it is this theory which makes it possible for us to combine the two domains of physics which heretofore we were compelled to regard separately. Therefore all propositions which were applicable in the one case are applicable in the other, an advantage which never was and never could be obtained by the mechanical theory of light. Previous to the introduction of the electro-magnetic theory of light the subject of physics was subdivided into three distinct parts—the mechanics, the optics, and the electro-dynamics. Their unification constituted the last and greatest task of all physical research. Inasmuch as the science of optics could not be made to conform or be brought into agreement with the mechanical science, it was inseparably linked with the electro-magnetic science and in this way the number of separate sciences was reduced to two—the last but one step toward a complete amalgamation of all the physical sciences into a unity. That which Maxwell could only prophetically

predict was finally achieved a generation afterwards when Henry Hertz taught us how actually to produce the electro-magnetic waves which, during the researches and experiments of Maxwell, were purely a matter of calculation. Hertz, by his discovery, has brought to a conclusive triumph the electro-magnetic theory of light, according to which the electro-magnetic waves differ from thermo-waves and light-waves only by their (approximately) million times greater wave-length. While on the other hand that extreme of the optical spectrum which contains the slower frequency waves was extended in a manner heretofore undreamed of, so too the other end of the spectrum, that of the shorter wave-lengths, equally aligned and adjusted itself in the final development of the theory by the discovery of the Roentgen rays and the so-called gamma rays of radioactive substances, the latter having a still greater frequency. These rays are of precisely the same character as the light-waves; they, too, are electro-magnetic vibrations only of immensely shorter wave-length. That they are also subject to the same laws was furthermore corroborated by Professor Laue in his recent discovery of the interference phenomena of the Roentgen rays. It is remarkable how readily, in the field of physical literature, or we might say almost unobservably, the transition from the mechanical to the electro-magnetic viewpoint of the theory of light was consummated—a tangible proof that the quintessence of a theory in physics depends not so much upon the assumptions upon which it is based as it does upon the laws to which it leads. The fundamental principles of optics, confirmed by experience, remained unchanged, but they ceased to be interpreted mechanically, by a process of reasoning, as it were, but electro-magnetically and thereby the field of their application was enormously expanded.

Viewed from the higher standpoint achieved by these discoveries, the study of the subject of light, or if we wish to be more exact, the study of the subject of radiating

energy, presents the picture of a firmly established, evenly balanced, uniform and complete structure in which a place has been found for all the magnetic vibrations which apparently are so unlike but which—ranging from the Hertzian waves, a kilometer long, to the hard gamma waves, billions of which are needed to make up a centimeter—after all, are governed by the same laws of propagation and are in accord with the principle of Huygen's wave theory.

The human eye is almost totally eliminated; it appears only as an accidental reacting medium, highly sensitive, to be sure, but limited in its perception, for it is responsive only to waves within a very narrow spectral range, scarcely an octave in width. For the rest of the spectrum other receiving and measuring instruments such as the wave detector, the thermo-element, the bolometer, the radiometer, the photographic plate, which are adapted to record and measure the different wave-lengths, have taken its place. So we see that the disassociation of the physiological perception of the organ of sight from the realm of optics has been brought about in precisely the same manner as was the case in the realm of mechanics, where the conception of "power" has long ago lost its association with muscular sensations.

Lately, certain serious defects and imperfections have manifested themselves in this glorious structure, which threaten its very foundation. Not a few scientists even now are of the opinion that a fundamental revision of the theory is necessary. While it is safe to assume that the electro-magnetic theory of the nature of light will remain undisputed, the Huygenian wave-theory of light threatens to be seriously menaced, at least in some of its essential parts, by reason of certain facts newly discovered.

If we expose a piece of metal contained in a vacuum to the action of ultra-violet rays of light a certain number of electrons will be thrown out with more or less intensity; and, as the velocity does not essentially depend upon the

condition of the metal, especially not upon its temperature, it is safe to make the deduction that the energy of the flying electrons has its origin in the rays of light which fall upon the metal and not in the metal itself. This in itself would not be astonishing; for we might assume that the electro-magnetic energy of the light waves is converted into the kinetic energy of the electronic activity. That which, however, seemingly presents an unsurmountable obstacle for the substantiation of the wave-theory of light as expounded by Huygens is the fact first established by Philipp Lenard that the velocity of the electrons does not depend upon the intensity of the radiation but upon the wave-length; in other words, upon the color of the light to which the metal is exposed, and to such an extent that their velocity is the greater, the shorter the waves used in the experiment. By removing the metal further away from a source of light, such as an electric spark, the electrons thrown out will still have the same velocity, the only difference being that the number of electrons released per second will become correspondingly less when the intensity of the illumination is reduced.

The difficulty now lies in finding the proper answer to the question: When finally the distance from the source of illumination is so great that the light intensity almost entirely disappears—and still the electrons show no sign of any diminution in their velocity—from what source, then, does one of those flying electrons derive its motive energy? The supposition is manifestly this; that there must be an accumulation of light energy at the precise spot from which the electrons are thrown out, an accumulation which is entirely out of accord with any theory which presupposes that electro-magnetic energy travels equally in all directions conformably with Huygen's wave theory. Even if we assume that the transmission of the rays of light from their source is not uniform but sudden and irregular, similar to the flashes from a beacon light, the

energy of such a flash, being distributed and diffused equally in all directions, would ultimately spread over such an immense area that the radiant surface of the metal would only receive an infinitesimal portion of its rays; and we can easily compute that under ordinary conditions, minutes and even hours must elapse before even one electron can attain the velocity which it receives from the radiations, these being in turn dependent upon the color of the light. Whereas, as a matter of fact, the action takes effect immediately, and so far we have not been able to ascertain that any appreciable period of time elapses between the exposure and its resultant effect. Precisely the same effect is observed when either Roentgen rays or gamma waves are substituted for the ultra-violet rays; only that, in this case, due to the shorter length of these waves, the rapidity with which the released electrons travel is correspondingly greater.

The only feasible explanation of this perplexing phenomenon seems to be that the energy sent out from the source of light remains concentrated, not only in point of continuance in time but also in point of position in space, in certain accumulation spots; or, in other words, that the light-energy does not distribute itself with perfect evenness and equality in all directions, in a continued and endless rarefication but, on the contrary, certain definite quanta thereof, dependent upon the color of the light, remain concentrated, only to be dispersed afterwards, with the velocity of light, in all directions. Each quantum which comes into contact with the metal can, in turn, impart its energy to an electron; this energy naturally remaining constant no matter how far the source of light may be removed.

We see here Newton's emission theory resurrected in another form; but the principle of interference of light, which blocked the development of Newton's corpuscular theory, also looms up as an unsurmountable difficulty in the conception of the quantum theory of light, for it is at present

difficult for us to conceive how two quanta, similarly constituted and flying independently through space, can meet and at their common point of contact neutralize one another without violating the laws of energy.

Under these conditions it becomes incumbent on the theory of radiation to make every effort to extricate itself in some way from a dilemma which is fraught with danger for either side. An attempt at an explanation might be made by assuming that the energy of the electrons thrown out from the metal is not derived from the rays themselves, but from the metal, and that the radiation simply tends to liberate the electrons in much the same manner as a minute spark, when applied to a barrel of gunpowder, will release any amount of pent-up energy. We must, however, then make the further assumption that the amount of energy released is entirely dependent upon the manner in which it is set free.

What has been advanced here as an attempt to explain the nature and action of light is equally applicable when we search into the cause of light, or rather when we trace the light-waves to their original source. Recent investigations, while they have given us an amazing insight into the laws of Nature, are here, too, confronted with new and almost unfathomable problems. This much is certain, that the light quanta referred to are destined also to play an important and characteristic part in the investigations as to the origin of light.

According to the bold hypothesis set up by the Danish physicist, Niels Bohr, the serviceableness of which has recently been astonishingly verified in a number of instances, a swinging of electrons takes place in every atom of a luminous gas, and these electrons travel in greater or smaller numbers and at different intervals around the heavy nucleus of the atom along very definite paths, yet in accordance with the same laws as those which regulate the movements of the planets around the sun. The light which also has

origin in those vibrations is by no means sent out into the surrounding space as uninterruptedly and uniformly as, for instance, the sound-waves from the prongs of a vibrating tuning fork, but the emission of light takes place abruptly and in jerks; for it is not dependent upon the regular vibrations of the electrons themselves but occurs only when these vibrations undergo a sudden transformation, a certain inward collapse, indeed a kind of interior catastrophe, we might say, which throws the electrons out of their original path into more staple paths of reduced energy, and it is the surplus remaining of this energy which, as it deserts the atom, travels, as a light quantum, out into space.

Perhaps the strangest part of this phenomena is that the duration of the emitted light, that is to say its color, is not in the least connected with the duration of the electronic vibrations either in their original or in their later paths but, on the contrary, is directly and exclusively controlled by the amount of the emitted energy. As the light quantum increases in proportion to the rapidity of the vibrations, an increased amount of energy, considered as a light quantum, will have a correspondingly shorter wave-length. When, for example, a great amount of energy is discharged ultra-violet or even Roentgen rays will result. When, on the other hand, only a small amount of energy is discharged, red or even ultra-red rays will result. At the present time, however, we are entirely at a loss for an explanation which accounts for the fact that the vibrations of the generated light occur with the utmost regularity as mono-chromatic rays.

We might indeed be tempted perhaps to regard all these conjectures as the vagarious offspring of a flourishing but idle fancy. When, however, on the other hand, we consider that it may be possible by the application of these hypotheses for us to render intelligible at one stroke the mysterious structure of the spectrum of the various chemical elements and especially to explain, with an accuracy which

enters into the minutest details and not only compares favorably with, but in some instances even surpasses the heretofore most exact measurements (as first demonstrated by Arnold Sommerfeld), the complicated laws which govern the arrangement of the spectral lines, in the examination of which numerous physicists have with untiring application labored strenuously for decades, and concerning which an enormous mass of valuable data has already been collected and classified — then we cannot fail to receive the impression that we have once more succeeded in lifting the veil and in obtaining a glimpse into the mysteries of mother Nature, and are forced to admit that these light quanta, at least during the moment of their generation, have an actual existence.

Philadelphia, Pa.

A New Theory of Vision

*Dr. Fritz Schanz**

being a

Translation of the Original Article in

Zeitschrift für Sinnesphysiologie

by

Edmond E. Blaauw, M.D. and Charles Sheard, Ph.D.

IN illuminated albuminous solutions less-soluble albuminous substances form at the expense of the more-soluble ones. These changes are produced by the more refrangible light-rays, which become absorbed by these solutions and produce fluorescence.

In Nature we also find that the light of shorter wave-lengths is biologically active. In order that these reactions may occur it is necessary that sensitizers be present, *i. e.*, substances which will serve as indicators of the reactions. Such sensitive substances are dyes, which form stable combinations with the albumins. These dyes absorb such rays as are complementary to the color of the substances which are sensitive and thus cause them to act on the albumins. That which the writer has found to be true for lifeless albumin, has been studied quite extensively on living organisms. From the amoeba on up until man is reached, it is found that all organisms can be rendered sensitive.

Special experiments have been performed to explain the physical processes of the sensitization process. In physics much work is being done on photo-electric actions; for example, the so-called "Hallwachs effect." This photo-electric effect consists of the emission of electrons from the illuminated substances due to the action of light. These electrons are carried to an appropriate receiving electrode, an

*We record, with sorrow, the fact that a brief statement of the decease of Dr. Schanz has appeared in the *Journal* of the *American Medical Association* for Feb. 17, 1923 on page 489.

electric current is thus set up and this is measured by an electrometer. In order to eliminate the influence of ordinary gases, the experimental material is put under a suitable container in which a good vacuum is maintained. Such a combination is known as a photo-electric cell.

Experiments had been carried out which demonstrate that fluorescent dyes show photo-electric effects to a high degree. Among them are many dyes which are known as sensitizers. I started from these experiments[1] and have been able to confirm the fact that those dyes, which may be classed as easily rendered sensitive, show to a high degree the photo-electric effect, and I was then able to demonstrate that albumins also show photo-electric reactions. To find out how the photo-electric actions of the sensitive substances and of the albumins influence each other, I have determined the photo-electric properties of solutions of sensitizers. After making these solutions in a similar manner with both distilled water and with dialyzed albuminous solutions, I again determined their photo-electric reactions. The photo-electric dispersion of the sensitizer solutions was much more diminished by the addition of the albuminous solutions than by the addition of distilled water. In order to explain this phenomenon we must believe that the electrons emitted by the sensitive substances are captured by the albumin molecules and so bring about the phenomena which I have demonstrated experimentally.

This optical sensitization is not only found in the organic substances of living Nature, but can also be demonstrated in inorganic substances. The Becquerel effect proves this to us. If two identically equal metallic plates are put in an electrolytic solution and the two plates are connected, an electric current is produced when the one plate is illuminated and the other one remains in the dark. The electric current is increased when a dye, known to be a sensitizer, is added to the electrolyte. The same process, I am convinced, is the basis of all sensitization processes in living matter.

These investigations give us an insight, therefore, as to why the sun acts as motor in the machinery of all earthly life.

If these observations relative to the elementary actions of light in Nature are correct, then the same process must be at the basis of the visual act. Light can act only when it is absorbed. We have considered the rods and cones to be the elements sensitive to light. We are to conclude, therefore, that they are unable to equally absorb the visible light rays. These light rays are, however, absorbed by the pigment in the pigment-epithelium of the retina. We have, then, the right to surmise that electrons are emitted because of the light absorbed in the pigment-epithelium in the same way as from the numerous pigments examined. The rods and cones of the retina act then as the receiving electrodes which capture the electrons in a manner analogous to the investigations on photo-electric effects. Electrons of different velocity are emitted by light of different wave-lengths. The stimulation set up in the rods and cones is conducted through the retina and optic nerve towards the central receiving organism. We can measure these effects in the optic nerve as the currents of response.

Brossa and Kohlrausch[2] illuminated the retina with monochromatic portions of spectral energy, measured the current of action and demonstrated that the initial portion of the current of action is distinctly steeper with short wave-lengths than with energy of longer wave-lengths. The shape of the curve was characteristic for every wave-length. They were never able, irrespective of wide changes in the intensity, to reproduce with light of longer wave-lengths the current-of-action curves obtained with short wave-lengths of light. The physiological process of vision must then be somewhat as follows: The incident light is absorbed by the pigment of the pigment-epithelium. The absorbed light causes an emission of electrons from the pigment. These electrons have different velocities according to the wave-length of the exciting light. Whenever the electrons impinge they produce

an electrical excitation, *i. e.*, the current of action, which is influenced by the characteristics of the velocity of the electrons which gave rise to it. The current of action stimulates the visual center. As against this theory one will directly propose the query: How does it explain vision in albinos? I myself had raised this objection, but upon looking over the literature I was pleasantly surprised to find that the findings in albinotic eyes did not disprove, but were rather in favor of my views. In all albinotic eyes, which have been examined, without exception pigment has been found in the pigment-epithelium, even when the other ocular parts and the rest of the body were entirely free of pigment. The entire literature of this subject will be found in my contribution *On Vision* before the Vienna Meeting of the German Ophthalmological Society (1921)[3].

The findings in retinal detachment also favor my view. In nearly every case the pigment is found detached from the rest of the retina, remaining with the choroid. The detached portion of the retina loses most completely its excitability. When the retina becomes re-attached and in contact with the pigment-epithelium, then its excitability becomes restored. In flat detachments the excitability is sometimes not entirely lost. In that case the electrons emitted by the pigment-epithelium can still reach the rods and cones and produce a feeble sensation of light. Sometimes we find that the sensitiveness to response of such detached parts changes with change of posture. With the change of posture the fluid layer below the detached portion also changes and thus modifies its distance from the pigment-epithelium and therefore affects its responses. To explain these processes one must surmise that the regeneration of the visual substances takes place in the pigment-epithelium. The visual substances are still hypothetic entities. The visual purple has been demonstrated to be present in the rods only. This is insufficient to explain the processes which take place in the visual act. There must be electrons which are emitted from the pigment

of the retina with different velocities and thereby produce excitation in the rods and cones.

How Can This Theory Explain Color Vision?

Electrons of different velocities correspond to the light of different wave-lengths. Thus there originate the sensations of pure colors as seen in the spectrum. We rarely see pure colors in Nature. We see color-mixtures in our surroundings. Numerous color-mixtures exist which our eyes cannot distinguish from the pure spectral colors. The ear is capable of analyzing tone-mixtures but the eye does not possess the faculty of analyzing color-mixtures in the same manner.

When color-mixtures act upon our eyes, electrons with different velocities are simultaneously emitted from the pigment-epithelium. Such color-mixtures should produce in the central receiving organism the same impression as pure colors, which are produced by electrons of a single velocity. In order to accept and to explain this phenomenon we must take it for granted that the projected electrons initially influence each other in their velocities, the more rapid ones accelerate the slower ones, while the slower ones retard the more rapid. The velocities thus become equalized and somewhere in their path a point will be found where the velocities have become uniform. A color perception arises only if these electrons meet the central receiving organism after equalization of their velocities. This velocity corresponds to that of the electrons which have pursued their entire path with a velocity which is the same as that acquired by the electronic mixture at the end of its journey. In both cases electrons arrive at the central receiving organism with the same velocity and produce there the same stimulus. The eye is unable to differentiate between these two impressions. We will take an example: Electrons, which are emitted from the pigment-epithelium by wave-lengths 400 and 500$\mu\mu$, can have, when they reach the central organ, a velocity the

same as electrons which are emitted by light of wave-length 450$\mu\mu$. The ray-mixture of 400 and 500$\mu\mu$ would then produce the same color impression as the rays of 450$\mu\mu$. Any explanation of the peculiarities of the color perception is still lacking. But I believe it is given here following out a well-known law of physics.

How Does the Perception of White Arise?

As we demonstrated in the example, wave-lengths of 400 and 500$\mu\mu$ can produce the same color perception as wave-length of 450$\mu\mu$. When, however, there is a mixture of wave-lengths 400 and 600$\mu\mu$ a complete balance of the velocities of the electrons in the same path cannot take place. When the electrons reach a receiving terminal and comingle they will not be capable of producing the perception of a spectral color. We perceive a visual impression as white when the electrons show the greatest differences in their velocities on mixing with each other. If in the same way wave-lengths of 600 and 700$\mu\mu$ are mixed, and if the velocities of the electrons are equalized before the central receiving organism is reached, we shall again have an impression of a spectral color which occupies a position midway between the exciting wave-lengths. If, however, wave-lengths of 600 and 800$\mu\mu$ are mixed, an equalization on the same path will be impossible. The differences of the velocity of the electrons will be the same, as in the mixture of the wave-lengths of 400 and 600$\mu\mu$. This mixture of wave-lengths therefore also will produce the impression of white. If the rays of the entire spectrum are mixed the same perception must originate. Here we have the explanation of the genesis of the complementary colors and the explanation of the origin of white through the mixing of complementary colors and of all the spectral colors.

If two simple colors, which in their positions in the spectrum are less distant than complementary colors, are mixed together, this mixture produces a color intermediate

between the two, and this color approximates the more closely to white the greater the difference of wave-lengths of the colors mixed. This result can now be explained. The nearer the colors are to each other, the smaller the differences of velocity in the electrons, giving rise to them, the quicker they become equalized in their course toward the central receiving organism, the more saturated becomes the color-impression which they produce, and the more closely the second color corresponds to the complementary color, the larger will be the differences of the velocities of the electrons when they reach the central receiving organ, and the more the mixture will incline toward white.

Approximate numbers are chosen in this exposition for quicker and easier comprehension. The arbitrarily complementary colors would be approximately separated by a difference of 200$\mu\mu$. How nearly does this correspond to what is actually so? Helmholtz, in his *Handbuch der Physiologischen Optik*, gives measurements of his own eyes and of four other observers. They show that the complementary colors in the middle of the spectrum are separated by about 110$\mu\mu$. The difference becomes larger when one of the colors lies at the end of the spectrum. In this case it is about 130$\mu\mu$.

These investigations upon complementary colors have given an explanation of a fact as yet unexplained. No complementary colors exist for the wave-lengths 500-560$\mu\mu$. The explanation is given in the above demonstrated origin of complementary colors. For these wave-lengths those radiations which influence the velocities of the electrons in the same way as in other complementary color-mixtures are absent. Complementaries to these rays would lie in the ultra-violet region. These are, however, absorbed in the tissues in front of the light-perceiving elements. Aphakics see a longer spectrum. The part which produces this lengthening of spectrum must be complimentary to a portion of the wave-lengths between 500 and 560$\mu\mu$.

An opportunity is here afforded to test the merit of our

theory. I have experimented somewhat in the following way: I produced the spectrum of an arclight with a quartz spectrograph. This spectrum was projected onto a surface so arranged that a screen of black paper, containing openings, could be put over it, thus cutting out any part of the spectrum desired. Behind the surface, on which the spectrum was received, a large quartz lens was placed and in its focus a porcelain plate was placed. Porcelain was chosen because it does not fluoresce in ultraviolet light. This slab was easily movable in the axis of the light-cone which formed in the focus of the quartz lens, so that, if parts of the spectrum were screened, these could be separately received and could be easily united. With this instrumental arrangement I have determined first of all for my own eye the position at which I could get no sensation of light. Prof. K., whom I had operated years ago for cataract and who has normal vision with appropriate lenses, had still a distinct color impression in this position. He designated the color seen as violet.

We thus determined if, within the range of 500-560$\mu\mu$, a position could be located at which the violet color impression changed into white. On account of the somewhat stronger intensity of this spectral region it had to be weakened by a neutral gray glass. It was then not difficult to determine the wave-lengths which were complementary to the ultraviolet ones, to which the observer was exposed. They are in the region of 546-552$\mu\mu$. The person then distinctly noticed a white streak in the violet field. If instead of this ray-region the part of 535-540$\mu\mu$ was presented the impression of pure white was no longer produced. The formation of the complementary colors, as I have above explained, corresponds therefore with actual facts. This constitutes the first experimental proof of the truth of my theory.

In my explanation I have left untouched the place at which the electrons produce the electric current, which we

measure as the response current. It is improbable that the electrons are actually conducted into the visual center; probably they produce the current at the base of the rods and cone cells. As is mentioned in the above cited investigation of Brossa and Kohlrausch, the current of action shows peculiarities, when produced by monochromatic radiations which are characteristic for the different wave-lengths of the exciting light. The peculiarity lies chiefly in the fact that the primary energy is the greater the shorter the wave-length of the exciting radiation. The first ascent of the current of action is therefore steeper with light of shorter waves than with longer radiation. It would be a second proof in support of the truth of my theory, if it could be demonstrated that the electric currents which are obtained in investigations on the photo-electric effects showed the same peculiarities and properties as the current of action at the retina. Such experiments I have found in the literature. The first experiments along this line were carried out by E. Ladenburg and can be found in his: *Über die Anfangsgeschwindigkeit und Menge der Photoelektrischen Elektronen in ihrem Zusammenhang mit der Wellenlange des auslösenden Lichtes*.[4] Ladenburg also has investigated various substances with spectral radiations and demonstrated that the primary energy of the electric currents thus produced depends also on the wave-lengths of the exciting light and that the current-curves rise more rapidly with short wave-lengths than with radiation of longer wave-lengths. These experiments have been often repeated and elaborated. This would demonstrate the identity of both processes. With the identity of the two processes is also demonstrated the truth of my theory. Among the physiologists, Prof. Garten[5] has expressed himself. But I do not believe that his observations bring any proof against my theory.

In short I can substantiate my theory:

Conclusions

1 By the proof, that color vision can be explained by known laws of physics without any vitalistic hypothesis.

2 By the experimental demonstration that there is a portion of the region 500-560$\mu\mu$ which is complementary to radiations from the ultra-violet region.

3 By the demonstration that the retinal currents of response and the electric currents which are obtained in investigation on the photo-electric effects show similar characteristics.

4 The best proof, however, seems to me to be that light in its relation to the act of vision does not in the last analysis act differently upon the retina than anywhere else in Nature. My contributions[6] upon the biological effects of light afford ample proof upon this matter.

Buffalo, N. Y.

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Editorials

The Editor and the Publishers of the *American Journal of Physiological Optics* do not hold themselves responsible for the opinions expressed by the various contributors. From time to time there are articles, appearing in this *Journal*, with which the Editor and doubtless many readers cannot agree, either in whole or in part, as to the methods pursued or the conclusions reached. Such articles are printed in the hope that they will stimulate further investigation and research. The great discoveries in the scientific world have been made by men and women who have had the courage to depart from the "beaten path." "Herd thinking" is rarely conducive to "creative thinking." This is the spirit in which the articles in each and every issue of this *Journal* are presented to the readers.

The Dominant Eye—In Particular, its Significance in Strabismus and in Muscular Imbalance and Duction Tests

AS we have previously pointed out (this *Journal*, Vol. 3, p. 49, 1923), in the majority of individuals one eye is the dominant or fixation eye, while its mate is simply the "follower-up" in the act of binocular single vision. Each eye, therefore, has its distinct function to perform. If, for example, the right eye is the fixating or directing eye, then, in so far as is conveniently possible, the object looked at will be sighted by the right eye in its own direct line of vision, while its mate—in this illustration, the left eye—will take up the function of verting or do the actual turning. Hence the left eye must, in this instance, carry on the function of *actual* motion in the act of convergence.

The *dominant* eye is, therefore, the eye which sights or *fixates* the object and which, all other things being equal, involuntarily acts through the function of accommodation to the end that the object is seen as *distinctly* as possible: the *non-fixating* or non-sighting eye, on the other hand, is not fundamentally involved in sighting or in the initial

impulse to distinct vision but is the *moving* eye. This moving eye, therefore, operates in harmony with the sighting eye and functions in the act of convergence to the amount necessary to afford binocular single vision by moving or swinging through the requisite number of degrees.

Without doubt, it is true that all objects looked at, especially those which are at arm's length or thereabouts, are not viewed with the mathematical perfection of distinct function outlined in the foregoing paragraph or in the article to which reference has been made. And yet casual observations which anyone can make, of those who read the newspaper in the street cars or of those who write or read at their desks will substantiate the fact that reading or other close work is done most comfortably when the dominant eye is very nearly, if not exactly, in line with the object being observed; or at any rate, when the object is so placed that the function of accommodation is dominated by the directing eye.

Visual Triangles

Our text-books and other treatises have always diagrammatically represented the fixation of close objects in binocular single vision through the use of an *isosceles* triangle, with the point fixated lying on a median line which represents, approximately, the perpendicular bisector to the base line joining the eyes. In reality, however, from eighty to ninety pairs of eyes out of every hundred possess a definite directing and fixating eye. As a result, therefore, the visual triangle should be drawn as a *right-angle* triangle—the right angle being assigned to the dominant eye—rather than as the customary isosceles triangle.

It is said that, when the head is held erect and the eyes look straight forward at a very distant object on the horizon, they are in their *primary* position. In this situation, with fixation at infinity, theoretical parallelicity of visual axes

exists and the matter of dominance of one eye or the equal division of function between the two eyes is of no consequence, since there is normally no demand upon either accommodation or convergence. That is, it is of no significance in "infinite" fixation whether the center of coördinates be taken at the nodal point of one eye or at the point where the median plane bisects the line joining the nodal points of the two eyes. But the various discussions on horopters, isogonal lines (circles or surfaces) entered into by Maddox, LeConte, Savage and others, have had to do with surfaces all points of which, when fixated, require an equal amount of convergence. In all instances, however, these circles are bisected by the extended median plane of the eye and are constructed through two common points (the nodal points or the centers of rotation) of the two eyes. Such considerations may be taken as the theoretically ideal set, but in general they are not found to exist. However, an extremely important and interesting deduction is to be drawn from the work of Maddox (*Tests and Studies of the Ocular Muscles*, pages 87-94), to wit: If the lines of equal accommodation and equal convergence are superimposed, *three points* are to be found in which the *proportion between accommodation and convergence is the same.* These three points are: (a) The primary straight-away fixation line—which is a line bisecting the base line joining the centers of the two eyes—making equal angles of convergence, thus diagrammed as an *isosceles triangle*, (b) a point, situated to the right of the one referred to in (a) above, at a distance equal to the intra-ocular distance; hence a condition in which the point fixated is much closer to the right than the left eye, thus giving—especially under usual reading and working distances—an approximation to a *right angle triangle* with dominance of the right eye, and (c) a point, situated to the left of the one referred to in (a) above, at a distance equal to the intra-ocular distance, hence approximating a *right-angle* condition with dominance of the left eye.

Proportionate Accommodation—Convergence Relationship

Furthermore, most objects looked at, and for which nicety of accommodative and binocular single vision adjustments are required, lie in a plane, as in reading a book. There is, then, but one position of equal accommodation and equal convergence, and that is along the perpendicular bisector or median to the base line of the eyes. Every departure of the point of fixation from the median line lessens the required accommodation in the opposite eye, while at first it increases that of the eye on the same side until the fixation point has moved over a distance exactly equal to *half* the interpupillary distance, when it again decreases.

If these two foregoing considerations—namely, (1) intersection of circles of equal accommodation and convergence, and (2) the difference in accommodation of eyes fixating points in a horizontal line—be borne in mind and if, in addition, the tangent plane to the circle of equal convergence at the point of intersection of the median line is considered, it can then be shown that the *exact proportionate accommodation-convergence relationship* for each of the eyes respectively,—although by no means the same quantity of either accommodation or convergence in each of the two eyes—is fulfilled at three points: *i.e.*, when the fixation is (a) on the median line perpendicularly bisecting the base line joining the centers of the two eyes, (b) in the line forming an approximate right-angle with the base line of the eyes at the right eye, or when the right eye is the dominant, fixating eye and (c) in the line forming an approximate right angle with the base of the eyes at the left eye, or when the left eye is the dominant or fixating eye. Such being true, therefore, there is no violation of the principle of minimum energy or incoördination of functions at these three fixation points. Hence Nature has three apparently equally desirable modes of visual functioning in so far as

binocular single vision is concerned. We believe that data show that from 75 to 85 per cent of all persons have a dominant or directing eye, hence in a large percentage of cases Nature and habit have not elected to leave the two eyes equally dominant but there has been developed a condition of *fixation* in one eye with *convergence coördination* in the other.

Tscherning's Remarks

In that extremely readable book by Tscherning (*Physiological Optics*, 2nd Edition, p. 308, 1904) in his chapter on the "Projection of Visual Impressions," he discusses briefly the topic of center of projections and the *directing* eye, as he names it. He writes: "In my case this center of coordinates coincides almost exactly with the right eye, probably because, having used it so much separately, I have acquired the faculty of judging exactly with this eye the position of exterior objects, or, in other words, because there is developed a kind of uniocular vision in addition to binocular vision. I must add, however, that this condition was not developed as a result of my labors on physiologic optics, because the phenomena were the same when, twelve years ago, I began to devote myself to this subject."

Further along he says, in the course of his description of three methods of proving the dominance of one eye: "I have also noticed, especially when I observe the double images of near objects, accidentally and without trying to, that one of them, that of the right eye, presents a more material appearance, while the other resembles a kind of shadow* * * *. It must be remarked that my two eyes are practically alike."

Tscherning's personal observations in the foregoing paragraph are readily explained. For the right eye, when the dominant one, exercises the function of *accommodation* predominantly, whereas its mate, the left eye, does the actual turning or *dissociating* act. The image seen by this eye is

"shadowy" for two reasons:—(1) The function of accommodation is not exercised to the same amount as in the directing eye and (2) the image is not formed at the fovea.

In a footnote Tscherning writes: "According to a communication from Javal, the binocular vision of Vallée was like mine. He described this condition as general and gave the name directing eye to the eye which controls projection outwards."

Incidentally Tscherning mentions Hering's experiment. This investigator's observations show how one eye may remain quite stationary while its mate moves. This experiment of Hering in no wise invalidates the generally accepted rule that all the innervations of the eyes are equally divided between the two members, but still substantiates the general principles which have been laid down by us with reference to the dominant eye, as well as affording a sound basis for much that follows in this paper. Hering's experiment is somewhat as follows. With the eyes looking straight forwards at some very distant object, let the gaze then be directed to a near object lying in the line of sight of one of the eyes; for instance, the right eye. The right eye has no motion to make in fixating it, while the left eye has to turn through a considerable angle. Hering has shown that half of the motion of the left eye is due to the converging innervation and the remaining half to the innervation which turns both eyes to the right and that, while the two innervations are additive in the case of the left eye, they exactly counteract each other in that of the right. Every increase in converging force in the right eye is instantaneously prevented from moving the right eye by an equal increment of abducting innervation.

Gould's Comments on Dominant Eye

In searching through the literature which we possess in our own library, and which is therefore readily *available*—the one great advantage of having and keeping a well-

selected, comprehensive collection of books and journals along one's own line of professional or occupational interests—we find a few interesting references and discussions as to the dominant or directing eye in operative or refractive practices. We may be pardoned for the insertion of some excerpts from these articles and this, too, irrespective of the fact that we are not in agreement—either wholly or, in some cases, even partially—with some of the quoted statements, especially some of those which follow in the immediately succeeding paragraphs.

The late Dr. George M. Gould, in an essay on "The Pathologic Results of Dextrocularity and Sinistrocularity" (*Biographic Clinics*, Vol. III, pages 363-373, 1905 and read before the meeting of the American Ophthalmological Society in 1904) says:

"It hardly needs the saying that the accidents of ocular diseases, keratitis, fundus lesions, cataract, high ametropia, heterophoria, amblyopia, etc., may put out of function, or threaten to do so, the primary—that is, the naturally, logically and neurologically—*dominant* eye, and thus the eye of the other side must be used as a makeshift and educated to become the secondarily dominant one. The older the age at which this occurs the greater the difficulty and the more of a tragedy will it be to the patient. There arise a hundred problems."

(1) "In all operative procedures there should be an exceptional striving to save the dominant eye. I do not believe in operations for this purpose, but if only one eye can be straightened and made functional in strabismus, by all means let it be the dominant one. The strabismus of a naturally dominant eye will be more easily cured than that of the non-dominant one. In double convergent squint the dominant eye should be the first one chosen to save."

(2) "The supreme value of the dominant eye makes it highly important that ametropia shall be corrected at the earliest day and year possible* * * * . Dextro-manuality,

or its opposite, is pronounced in children of less than a year, and the location of the speech center is being fixed rapidly, and often unchangeably, at two or three years of age."

(3) "If saving of the naturally dominant eye is impossible in the young child, and its fellow must be secondarily educated into dominancy, it becomes a question if the child should not also be taught to write, eat, etc., with the corresponding hand."

(4) "In the adult the dominant eye I have found will preserve its dominancy despite a considerably higher degree of amblyopia, ametropia, etc., than that of its fellow.* * * * I doubt if the naturally dominant eye would retain its dominancy if it had, say, an acuteness of only 20/50 while the vision of the other was normal. This fact arouses a number of queries in the mind of the refractionist. One of these would refer to the inadvisability of giving the non-dominant eye a greatly superior acuteness of vision by means of glasses. In an adult such a sudden change, even reversal, in the habits of part of a lifetime might be brought about that the spectacles would not be tolerated and failures of various kinds ensue."

(5) "An axis of astigmatism in the dominant eye from 10° to 20° to either side of 90° or 180°, while the axis in the fellow eye remains normal or unsymmetric, produces head-tilting.* * * * It is evident that an axis in the dominant eye only 5° to one side of 90° or 180° would hardly produce a noticeable tilt of the head, or might possibly be compensated for by the rotation of the eyeball itself. It is possible that some types of heterophoria, and especially cyclophoria, may be explained as arising from the compensation of the ocular structures instead of producing the tilt or cant of the head."

(6) "An ametropia in the non-dominant eye which tends to throw it out of function is much more likely to result in mal-function, non-function and disease of the eye. Many practical suggestions and rules result from this fact both in refraction work and the management of inflammatory

diseases. In amblyopiatrics, for instance, it is perhaps as well not to strive to give the non-dominant eye an exceptional, or even an equal, acuteness of vision."

With these abbreviated quotations from the writings of Gould we find ourselves only in partial agreement. With his emphasis of the importance of the dominancy of one eye in refractive and operative treatment we are in agreement, but in certain particulars we feel that a procedure exactly opposite to that suggested by Gould would be proper. There is, for example, a distinct, fundamental difference between a *binocular* and a *monocular* squint.

When a *monolateral* strabismus exists, Nature has already previously determined the dominancy of one eye, for it is the fixating eye, and its mate takes up the deviation or is the moving eye. This is in conformity with the usual or normal conditions as found in a non-strabismic or non-squinting pair of eyes; for the usual state of affairs is one in which one eye is dominant and assumes the function of fixating or directing, while its mate is the moving eye and takes up the function of working in harmony with the directing eye to give binocular single vision.

In a case of monolateral squint, therefore, it would appear that, from the operative standpoint, nothing should be done in the nature of advancement or tucking of the extrinsic muscles of the dominant eye, but attention should be directed solely to the deviating eye. We cannot agree with the late Dr. Gould that there is a condition of strabismus present in a naturally dominant eye, for this eye is the fixating or holding eye, although all will grant the fact that when the fixing eye is screened it turns under the cover, while the squinting eye is directed toward the object which engages the attention unless the power of central fixation has been lost.

Usual Operative Procedure

And again, Hansell and Reber, in that most excellent little volume on *Ocular Muscles* (page 178)—unfortunately now

out of print—ask these questions:—"To what muscles should the operative treatment be directed? Should it include both eyes? They say:—"Inasmuch as a scientific restoration of binocular vision cannot often be obtained in monocular squint, and as all procedures are carried out with the object of removing the deformity, it has been argued that attention should be directed mainly to the squinting eye.* * * * The procedure which appears to offer the greatest advantage, is advancement of the externus of each eye, combined with a moderate tenotomy of the internus of the squinting eye. Subsequently, if necessary, tenotomy of the internus of the fixing eye may be performed," (in esotropia).

If the idea of the dominancy of one eye is correct and that, in the majority of cases, all of the actual converging is done by one eye (*vide* also an expression of this same notion by Dr. Major R. P. O'Connor, *Ophthalmology*, July, 1915), then it seems logical to say that, when an operation is necessary for insufficiency of convergence, for example, attention should be directed wholly to the non-fixing eye. From this standpoint, therefore, we should be in disagreement with Hansell and Reber and a good many others. Being only an interested student in and of operative procedures, I am open to severe criticism and to proofs to the contrary of the views expressed. But, knowing as we do that so many operations upon the extrinsic ocular muscles fail in many particulars, we may be pardoned if, out of this discussion, comes from the minds of others new methods of attack.

Prisms Placed Wholly before Deviating Eye

The general procedure proposed in the non-operative treatment of constant unilateral squint—and about 85 per cent of constant squints are of this character—is to continuously occlude the fixing or dominant eye with the obvious notion in mind of endeavoring to develop functions more

nearly approximating the normal eye in a non-squinting condition. A reasonably efficacious procedure, the writer feels, lies in a somewhat different method, namely: *the use of prisms placed wholly before the deviating eye.* This leaves the dominant eye at all times with its natural function which, incidentally, it loses under cover, for it tends to take up the squint. By the use of prisms, however, placed wholly before the deviating eye, the image of the test-object may be moved toward the fovea of the squinting eye. After both images have been located by the strabismic person, the two may be, in many cases, fused through the use of sufficient prismatic power. The prism power should then slowly be reduced to the point of diplopia. In this manner the weak extrinsic muscle (or muscles) is exercised: we should prefer to say that the appropriate nerve center is stimulated into action. If progress is made under this *modus operandi*, a prism for constant wear, placed wholly before the deviating eye, may be prescribed and as improvement is made its power may be reduced. It seems a fallacy to the writer, therefore, to use prisms for *exercising purposes* or to prescribe prisms for wear in monolateral strabismic cases through the use of prisms divided between the two eyes. On the contrary, we believe that the prism, either for exercise or for constant wear in such a case, should be wholly before the deviating eye, for the reason that every inducement should be offered to coördinate the moving eye with its fixing mate, and nothing should be done to lessen the dominance of the dominant eye. This does not mean, however, that the acuity of the dominant eye may not be reduced through over-correction (in concomitant convergent strabismus, for example) since such a reduction in acuity does not affect its function of fixation in such cases, for the reason that the vision in the squinting eye is generally much below that of the dominant one. We can, at least, commend to the consideration of others the use of prisms in the manner outlined, for it has proved worthwhile to the writer.

Dissociating Device before Non-dominant Eye

The question is frequently asked: In making ocular muscle imbalance tests, before which eye should the dissociating agent be placed? Will the data obtained be the same irrespective of which eye is allowed to be the fixing eye? Maddox and others claim that each of the eyes is free to fix either the spot of light or the Maddox rod streak. Maddox further says:—"If alternate fixation makes the streak shift to different figures (on the tangent scale) the case is one of either anisometropia or paresis." After a considerable amount of experimentation the writer believes that the distorting or dissociating device should always be placed *before the non-fixating* or *non-dominant eye,* when such a condition exists. By such a procedure, the directing eye looks at the natural test-object and definitely fixes it, while its mate, naturally accustomed to moving into coördination with the directing eye, will readily disclose its latency of error in this function of convergence coördination. In other words, with the dominant eye seeing the natural test-object, it will immediately assume its predominant function of fixating, and accommodating (if such is demanded), while the non-dominant eye will assume its natural function of motion. If, on the other hand, the dissociating device is placed before the dominant eye and the naturally non-directing eye is allowed to attempt fixation of the test-object, a conflict of functions is immediately set up and an uncertain, vacillating set of affairs is present. From numerous data available, we find that the tests on muscular balances or imbalances differ considerably when one and then the other eye carries the dissociating device. We believe we should expect marked differences. We have had cases of esophoria and exophoria, with test-object at 20 feet, vary as much as 5 to 8^{Δ} by the simple shifting of Maddox rod or similar device from one eye to the other. Very rarely have conditions of anisometropia or paresis been present in this long series of tests,

hence we conclude that the data obtained should differ in pairs of eyes having a dominant member. At any rate, we feel that the practice of putting the distorting or dissociating device before the non-dominant eye is the only truly correct procedure.

This conclusion is the same as that reached by Dr. Percival Dolman in a short but important paper on "The Relation of the Sighting Eye to the Measurement of Heterophoria." (*American Journal of Ophthalmology*, Vol. 3, p. 258, 1920.) He writes:—"Further analysis of the data does not help determine whether the greater or lesser amount of error represents the true condition of the eyes. If the purpose of the heterophoria test is to measure the maximum error, then the greater amount revealed by giving the sighting eye the rôle of fixation indicates a practical method of performing the test. This will give the greater amount of error in 66 per cent of the tests and be accurate in 17 per cent more where the same amount of error is recorded for each eye. It is possible then in 83 per cent of the tests for heterophoria made by the Maddox rod screen method to measure the maximum error by having the *sighting eye fix the light.*"

Furthermore, all these muscular imbalance examinations should be conducted as *monocular* tests. The reason is obvious if the significance of the dominance of one eye is appreciated and accepted. Nothing but the refractive finding should be placed before the dominant eye, hence the prisms which may be needed to measure up the amount of imbalance, or make the tonicity test, should be placed before the non-fixating eye, which also carries the dissociation accessories. Such a procedure is known as a *monocular* test, first of all taught or suggested, we believe, by Dr. G. C. Savage. But this monocular test need be made only with one set of conditions present, namely: the dominant eye fixing and the non-dominant one wearing the dissociating agent and the prisms measuring the heterophoria.

Duction Tests on Non-dominant Eye

And yet again, and finally, questions of procedure often arise in the matter of *duction* tests. Such questions are:—Is it necessary to make duction tests on both eyes? Are the ductions, as obtained with any specific point of fixation, the same for both eyes? If not, why not?

As a matter of routine examination we feel that it is of value to make the adduction and abduction measurements upon the non-fixating eye only. Let the dominant eye exercise its natural function of fixation and let the non-fixating or coördinating eye perform its essential function of motion in order to prevent diplopia. Each eye, under such a *modus operandi*, is functioning under conditions that exist in its everyday experience.

If, however, the non-dominant eye is made to attempt the rôle of fixation and the directing eye is forced, under the prisms administered, to take up the function of converging or coördinating, then we feel that data of no particular value may accrue. Generally the abductions and adductions for each eye, when a dominant eye exists, will not agree and they should not. The idea, therefore, of endeavoring to determine the so-called and improperly called "weak" muscle and to specify the weakness as belonging to either eye from a comparison of the ratios of adduction to abduction, appears to the writer to be folly. The ratio cannot be expected to be the same in the two eyes if a dominant eye exists.

In the case of the vertical ductions we should say that greater weight ought to be given to the data obtained upon the non-fixating eye. The dominance of an eye does not, in all probability, play as important a part in vertical as in lateral imbalances.

Conclusions

By way of résumé upon the significance of the dominant eye in matters of visual acuity, muscular imbalance and duction tests, the wearing of prisms, prismatic

exercises and operative procedures, we note:

(1) In eyes having equal acuity, leave the visual acuity of the dominant eye, all other things not indicating to the contrary, slightly superior. Under no circumstances, when such can be avoided, leave the acuity of the non-directing eye better than that of the directing member.

(2) In cases of anisometropia or in which the visual acuity of the dominant eye is not quite equal (say 20/30) to that of the non-fixing eye (say 20/20), it will often produce comfort and satisfaction if the acuity of the non-fixating eye is slightly reduced by additional convex lens power. Especially is this true in close work.

(3) All ocular muscle tests should be *monocular*.

(4) In testing for heterophoria, the testing device should always be placed before the non-dominant eye, the directing eye having nothing to interfere with its straight-away fixation. There is no reason for making a second series of tests in the reverse manner.

(5) In making duction tests, especially upon the lateral muscles, it would appear to be sufficient to make these duction tests upon the non-dominant eye. In vertical ductions, it is best to take them upon each eye in turn.

(6) In cases of tropias or phorias, in which prismatic exercises or like treatments are given, the whole of the prism should be placed before the deviating or non-fixing eye.

(7) If prismatic corrections are incorporated in glasses prescribed, then the major portion, if not the total in cases in which the total amount does not exceed 2^{Δ}, should be placed before the non-dominant eye. If 1 to 2^{Δ}, base in, out, up or down, are to be incorporated in lenses, they should be worn before the non-dominant eye. In other words, interfere to the least extent possible with the dominant eye in its function of straight-away fixation.

(8) In operative procedure, it would appear to be logical that all operations be confined initially to the squinting or deviating eye.

The Time Element Reduced in the Correction of Convergent Strabismus by Lenses

E. LeRoy Ryer, Opt. D.

THE method here advocated must not be looked upon as a panacea for all internal strabismic cases. There is no way of estimating beforehand to what percentage of such cases it may be applied with success. But that its results are most encouraging in those cases wherein it does apply is now beyond reasonable doubt.

We have all met the case of the child with one eye so crossed as to seem to be hiding behind the nose. It has been passed down as a much honored tradition, and so accepted, that lenses would have little or no remedial effect in such a case after the seventh year of age while up to that age their effect was conceded to be most efficacious.

The writer can see wherein lenses might not help at all but he questions the empiric seventh-year line of demarkation.[1]

If plus lenses correct the squint up to the fifth year what happens in the course of the next year or two to totally inhibit the corrective effect of such lenses? Surely there is no anatomic nor physiologic change at this period that properly accounts for it. Looked at from any angle the tradition is not well founded, yet as a matter of fact it is more difficult to correct a case of convergent strabismus at the seventh than at the fifth year, even assuming that the squint be due primarily to the accommodative effort exerted in correcting a facultative hypermetropic condition.

Casting aside all predisposition in favor of the limited age theory the writer concluded that the age, *per se*, had practically nothing to do with it but that some other factor

[1] In 1907 the author made the discovery that bifocal lenses, eliminating the extra accommodative action at the reading range as well as correcting the hypermetropic error for distance, caused convergent strabismus to disappear in children up to 14 years of age who had worn distance correction for years. The results of these investigations were published at that time in the *Review of Optometry*.

entered at about that age in essentially all cases. This factor seems to be that at about this age the average child starts to school and that the added factor that makes the squint so far more persistent is the added close work, involving of course added accommodative effort.

If one will take the trouble to differentiate the hypermetropic from the accommodative effort used in its correction the whole subject will be more readily comprehended.

Briefly, I assumed that if the accommodative effort used to correct a three diopter hypermetropic error created the convergent squint, certain reflexes might become so well established as to cause the usual three diopter accommodative effort used in reading at thirteen inches to maintain the squint thus established.

On this basis the correction of the three diopter hypermetropic error would eliminate the resultant squint so long as the eyes were used for distance chiefly, but upon using those same eyes for continued close work, as happens upon attending school, more accommodative effort is called for and must be relieved if the squint is to be suppressed.

Hence, instead of eliminating only the accommodative effort at distance by correcting only the hypermetropia, bifocals were ordered in these cases so as to eliminate the accommodative effort at near as well and the results were most gratifying.

Instead of crowding on so much plus as to fog distance vision, tempting any child to look over the lenses and lose their entire effect, the manifest hypermetropic error only for distance is corrected, maintaining the clearest vision possible and there is added from +1.50 D. to +2.25 D. for near use in the form of bifocals. Obviously I use some form of invisible bifocals (usually Kryptoks) to avoid the heartbreaking comments that are always so gratuitously offered in case visible segments are used.

The addition of +1.50 D. to +2.25 D. is an empiric rule based upon experience with this class of cases. The writer

has never found a case that would tolerate the full three diopter addition for the thirteen inch reading range.

At first it was assumed that the cases amenable to this treatment would be relatively rare because they had to be cases, it seemed, wherein the squint was due entirely to the facultative hypermetropia. But, while this is essentially true, it will be found in practice that by a little developmental work on an amblyopic eye or some fusion training, many a case of stubborn convergent strabismus is turned into one that readily responds to corrective treatment with plus bifocals.

In any case of convergent strabismus that can be made to respond to convex lens correction the results will be quicker and surer if bifocals are used to eliminate the extra accommodation at near ranges as well as correcting the distance error.

More persistence may be called for in older cases because of the more firmly established habits that must be overcome, but the results in my own practice fully warrant my urging that no case of convergent strabismus be submitted to surgical interference until bifocal relief of both distance and near-range accommodative efforts has been thoroughly applied and found ineffectual.

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Physiological Analysis of Ocular Discomfort

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HUMAN vision normally should be clear and binocularly single as well. To test one of these functions of sight and at the same time but superficially test or ignore the other, can never result in the best conclusions being obtained in the interest of the patient's ocular welfare. It is to be noted with interest, pathological cases excluded, that all cases with comfort or discomfort can be logically arranged into fifteen principal classes or innervational divisions. These are:—(1) Emmetropia, (2) hyperopia, with or without astigmatism and (3) myopia with or without astigmatism; each of these may be existent with orthophoria, esophoria, exophoria, hyperphoria, and cyclophoria.

A review of case records will reveal that hyperopia, with or without astigmatism, associated with esophoria constitutes the great majority of conditions confronting the refractionist for solution. Myopia with exophoria and hyperopia with exophoria will generally be found to be fairly equally divided in numbers. Practice and records of findings in selected communities may vary the numbers of this or that combination.

Hyperphoria is frequently found to be present and occasionally cyclophoria. Granting the existence of the exceptional case, it is generally agreed that correction of the existing ametropia has little or no effect on the disappearance of hyperphoria, while asymmetric astigmia, when corrected, will most probably cause the cyclophoria to disappear, if it is present.

This article will deal principally with those combinations involving the ametropias with the lateral heterophorias, since these constitute the very great majority of conditions coming before the refractionist.

It is to be noted, in the first place, that human desire for

binocular single vision predominates over the desire to see clearly. Uncorrected ametropes having subnormal visual acuity (blurred) will continue to make great effort to obtain binocular single vision, when heterophoria is present. Again, while it is true that in the absence of lens assistance the correction by the patient of relative hyperopia results in great difficulties of fixation and occasionally diplopia, still the latter is the exception rather than the rule. Certainly, as the effort to see clearly becomes increasingly difficult, the assistance of the forced hypertonicity of the interni is utilized in securing added innervation to the ciliary. But finally a choice must be made, either vision—double but clear, or binocular vision—single but blurred for points previously seen clear.

In the great majority of such cases, it will finally end in the latter and, since abnormal efforts are removed, increased comfort will ensue. The functional correction of relative hyperopia in youthful cases of high error associated with an incompleted, or retarded fusion desire will most usually result in strabismus.

The desire for binocular single vision, being faulty in such cases, would be no doubt subordinated to that of clear vision, hence there will be clear vision but strabismus. Cases of low uncorrected hyperopia, associated with a moderate to high exophoria at infinity, give us a clear illustration of this choice between clear and binocular single vision.

In excessively stimulating the convergence through the interni to correct the existing exophoria, the innervational influence is carried to the accommodation centers, with the result that accommodation tends to function or actually will take place, its actual manifestation being limited only by the individual's inherent or acquired ability to restrain or suppress it, in the interest of the desire for clear vision.

Many such cases are fitted with low minus lens corrections with perfect comfort for long periods of time. Such cases

are frequently mistaken for low true myopia. The minus correction, when given in such cases, will permit the accommodation which tends to accompany the actively stimulated convergence to take place and by the attending neutralization of it, results in a clear image. The necessity to suppress this accommodative action is thereby removed and the accommodative center, thus freed of suppression and restraint, assumes a harmonious relationship with the activily used convergence, and comfort will result.

If, as clear vision is maintained in the combination cited, the effort to sustain the suppression of accommodation becomes increasingly difficult, it is evident then that a choice must be made between clear and binocular single vision.

This time when the choice is made it is determined largely by the patient's ability to suppress the accommodative action. Vision can be quite clear, if diplopia were present. Binocular single vision can remain with vision blurred, perhaps not constantly, but at least intermittently. Such vision results in asthenopia from the nervous effort that is made in trying to suppress the accommodative action.

Should the quantity of such effort, which is maintained in the interest of clear vision, be slight as compared to the total effort possible, then it is reasonable to presume that comfort will prevail. Few such cases choose binocular double vision with clearness. Rather it is to be noted that clear vision is sub-ordinated, to the end that binocular single vision shall remain even though blurred, intermittently or constantly.

The monocular form of refractive examination will, by disrupting the fusion sense, permit the covered eye to diverge, thus releasing the third motor innervation to the interni. This release on the convergence centers will, in turn, release the innervational influence on the accommodative centers. Such eyes, binocularly requiring low minus, usually accept a low plus correction monocularly or should the case be true myopia, will accept less minus.

When, by the monocular method, each eye is corrected and then both are permitted to fix the letter chart, visual acuity will in many cases descend to 20/30 or occasionally to 20/60. In many such cases it will tend to become clearer as the patient continues to direct attention to the letters. Such increase in visual acuity is directly governed by the patient's ability to suppress the accommodative action in the interest of clear vision. Vision in some cases will alternately clear and blur under the above conditions, simulating an intermittent spasm of the ciliary muscle in its effect on visual acuity.

Reducing the plus monocular correction for hyperopia or increasing the minus for myopia will again cause vision to become binocularly clear. The dioptric difference between the monocular subjective prescription and the accepted comfortable binocular prescription is the measure of the accommodation which cannot be suppressed with comfortable effort. To more clearly illustrate this suppression effort together with the quantities involved a case record will be cited.

Mr. U. age 23, of good health. Prominent ocular symptoms were as follows: Has always had difficulty in vision, explaining that sometimes his vision is clear but most of the time blurred, with intermittent periods of clearness, mental confusion relative to sight, eyes tire. Has noticed that by adjusting eyes (his expression) he can see clearly but double.

V. A., O. D. 20/15
O. S. 20/15 O. U. 20/40 intermittently to 20/20

Heterophoria at infinity from 12 to 14 prism diopters of exophoria.

Monocular subjective prescription:

O. D. +0.50 D. S.	O. D., V. A. 20/15
O. S. +0.50 D. S. (A)	O. S., V. A. 20/15

O. U. 20/60 hazy

Monocular skiametric prescription similar.

Binocular static skiametric prescription:
—1.75 D. S. (B) V. A., O. U. 20/15
Subjective:
—1.00 D. S. (C) V. A., O. U. 20/15

Binocular visual acuity through monocular prescription "A" was 20/60 occasionally clearing to 20/40, but only for an instant. The difference between A and B is 2.25 diopters and represents the total accommodative effect resulting from the actively stimulated convergence.

The explanation for the higher binocular skiametric prescription (B) as compared to the binocular subjective prescription (C) is somewhat as follows: Since the working lens, which must be employed in skiametric procedure, results in greatly reduced vision for infinity, there is no need to suppress the accommodative activity in the interest of clear vision, as it is impossible to obtain clear visual acuity regardless of the effort put forth to secure it. Hence, a very close approximation of the total accommodative influence resulting from the convergence which functionally corrects the exophoria. Herein lies the value of skiametry, permitting the refractionist to observe and measure the refractive conditions with any innervational influence that may be present from anomalies of convergence.

The difference between the monocular subjective prescription (A) and the binocular subjective prescription (C) is 1.50 diopters and represents the amount of accommodation the patient could not voluntarily or comfortably suppress in the interest of clear vision. The difference between the binocular skiametric prescription (B) and the subjective binocular prescription (C) is 0.75 D. and represents the amount of accommodation the patient has suppressed in the interest of clear vision. This 0.75 D. suppressed accommodation is just 33 per cent of the total accommodative effect produced by the convergence, which was 2.25 D.

In passing, we note that the relation of one diopter of accommodation to meter-angle of convergence closely ap-

proximates the conditions in this case. Twelve prism diopters of convergence are required, being equivalent to about 2 meter-angles, while the total accommodative effect as determined is 2.25 D.

It is, of course, common knowledge that uncorrected facultative hyperopia, associated with esophoria of moderate to high degrees, will give the minimum prescription for the refractive error, when determined monocularly. The evident reason for this is that, since the covered eye actually will and does deviate inwardly, thus permitting the hypertonicity of the interni to become manifest, the attending innervational influence is carried over to the accommodative centers and results in ciliary activity, thereby requiring less plus lens correction under such conditions.

It is further to be noted that in almost every case of this nature, more plus lens power will be accepted binocularly without reduction in the acuity. The indicated reason being that—since in the interest of binocular single vision the externi are actively stimulated to correct the esophoria—the interni through the fusional centers are inhibited. This inhibitory influence being carried over to the accommodative centers results in a greater relaxation in the ciliary muscle than before, hence more plus lens acceptance binocularly. These cases and explanations have been advanced for the purpose of directing the reader's attention to the fact that clinical evidence, supported by the physiological manifestation of the ocular functions involved, warrant the contention that *convergence can and does cause accommodation to become active, the actual manifestation of such accommodative action being governed and limited by the individuals ability to suppress it in the interest of clear vision.*

Accommodation resulting from convergence effort, when permitted to take place, due to (1) inability of patient to suppress its manifestation in the interest of clear vision, (2) or when neutralized in whole or part by hyperopia (3) or low minus lens, does not result in accommodative asthenopia.

This stimulation of the accommodative center and function is not the result of an active desire to see clearly, but is a direct physiological reflex, carried over from the actively stimulated convergence centers. In other words, the accommodation so produced is a by-product of the convergence effort in correcting the exophoria, and as such the burden of the innervational effort lies directly in the convergence centers in maintaining binocular single vision. If, however, for any reason this form of accommodation is suppressed by the patient in the interest of clear vision, as results when too much plus lens correction is given to young hyperopes when moderate or high degrees of exophoria are present, or when corrected ametropes possess moderate or high exophoria for reading points, then discomfort is the rule.

The writer offers the following results, obtained from investigations carried on over a considerable period of time, in support of the contention that accommodation will and does result from excessive convergence effort—the amount of such accommodative action manifested being limited by the individual patient's ability, inherent or acquired, to suppress it.

In all, 68 individual tests were made, with results so uniform in general that additional tests of the same character were deemed unwarranted. Care was taken to select young healthy subjects, possessing very low ametropia or heterophoria or none of either. These cases were selected to insure a true innervational response to the tests, uninfluenced by the energy required or ability needed to suppress either, as would be necessary in the correction of moderate or high degrees of ametropia and heterophoria.

The average age of both sexes was 22 years; of the 68 tested, 2 were females. The largest ametropic prescription (presumably correct) worn by any of the subjects was +0.75 O. U. The largest measured heterophoria obtained in the group was 3 prism diopters and this was confined to lateral

imbalance. No hyperphoria was ascertained to be present in any of the group tested. In only two of the cases selected was cyclophoria revealed for infinity and this in no wise altered the general result obtained. In each case, the adduction to the point of diplopia (spot light) was measured, a moment's rest permitted and then re-tested on the illuminated letter chart.

The convergence so measured varied from 12^{Δ} base out to 42^{Δ}, base out, the general average being about 27 prism diopters. As the Risley rotary prism was gradually increased in power before each eye simultaneously a very fine demonstration of the activity of the desire for clear vision asserted itself, for the letters would alternately blur and clear. The amount of such prism causing this reaction, together with its relation to total prism overcome, varied so greatly for the group that no average obtained of this was deemed worthy of record.

In 17 cases, when the vision became blurred, it was found that this blur constantly increased; in 47 cases the blur became constant when the amount of prism power, base out, was from $^1/_3$ to $^3/_4$ of total prism diopters overcome. In 4 cases the blur became constant only when the amount of prism power, base out, approached closely the total overcome. These four cases were ascertained not to favor any special amount of total adduction. The total ability to overcome prism in these four cases was 16, 28, 34, and 38 prism diopters, respectively. From the tests, it appears that the ability to successively suppress such accommodation varies with the individual and no doubt fluctuates somewhat with the attention directed to the chart of letters. There was required in each case tested—with vision now blurred, the eyes also being under the influence of an amount of prism power previously ascertained to be nearly sufficient to cause diplopia—from a –2.00 D. S. to a –3.00 D. S. to again obtain and establish clear vision. This amount of minus lens power measures the accommodation which was forced into

operation by the action of the function of convergence in overcoming the prisms.

Twenty-six cases of the group were, in addition to the above test, skiametrically verified with almost identical results. Moreover, on removing the minus spheres and creating diplopia with added prisms, the letter charts became clear again, showing that, since the convergence effort was no longer in force, the accommodative activity subsided with it. Also, since the visual acuity through the prisms on each chart seen (when diplopia took place), was in most cases almost equal to the visual acuity obtained with the unobstructed eye, there is proof that the distortion of the prism was a negligible factor.

Some who said that, with the prisms in place and diplopia present, they could not read the 20/20 line, said it was clear. Granting that the distortion did affect recognition in a few cases, since the letters were clear, there is proof which would substantiate the former conclusion that the blur which resulted from the adduction trial was due to the accommodative myopia only.

There is also a host of clinical evidence, in any large group of modern case records, which sustains this contention that accommodation can and does cause convergence. Such convergence, which results from excessive stimulation of the accommodative centers, being a direct physiological reflex or by-product of the accommodative effort made in the interest of clear vision, has its innervational source directly in the accommodative center. And, conversely with the statement previously made, when such convergence is permitted to take place with the actively stimulated accommodation, no extrinsic muscular asthenopia is the rule as appears to be the case when uncorrected facultative hyperopia is associated with moderate exophoria, or when uncorrected myopia is associated with moderate esophoria for reading points. But if for any reason such convergence must be suppressed in the interest of binocular single vision,

as when moderate or even low facultative hyperopia is associated with esophoria or when low myopia is associated with moderate or high esophoria for reading points, then discomfort is the rule. From that which has been written, together with the results of a critical review of many case records of other refractionists, the conclusion is drawn that the *suppression of a natural function or habit will result in earlier asthenopic symptoms and mental reactions than excessive stimulation of the same function.* As applied to the ocular functions in particular, the *suppression of accommodation in the interest of clear vision, while convergence is stimulated in the interest of binocular single vision, or the suppression of convergence when accommodation is actively stimulated,* will result in earlier asthenopic symptoms than if both functions are simultaneously and excessively stimulated.

To illustrate: Esophoria is expected as a natural physiological consequence of uncorrected facultative or latent hyperopia. Yet when these co-exist, even in moderate degrees, discomfort is the rule. The accommodation here must be actively stimulated and the convergence suppressed.

When exophoria is associated with uncorrected facultative of latent hyperopia in favorable balance, rarely ever, until the presbyopic age is approached, is complaint made of asthenopia. Here we have the performance of natural functions, accommodation actively stimulated and convergence also, and while both functions are demanding excessive innervation but little if any discomfort prevails when efforts of each are fairly equal.

Exophoria is usually physiologically associated with myopia yet when these co-exist, discomfort is the rule for points in the range of clear vision of the uncorrected myope. Convergence must be actively stimulated, yet — if vision is to remain clear for the point so fixed — the accommodation must be suppressed, and, while the myope, through

habit and necessity is unusually adapted to so doing, asthenopia is the rule.

When esophoria and uncorrected low or moderate myopia of favorable balance co-exist, very little or no discomfort is experienced; both functions being simultaneously and naturally stimulated for points within his punctrum remotum. And, for the same reasons, the *orthophoric emmetrope, or the corrected ametrope with little or no muscular imbalance can use 3 D. of accommodation and 3 M. A. of convergence for reading at 13 inches for long periods of time in comfort, whereas, if similar stimulation of either function is attended or associated with but a moderate suppression of the other, such orthophoric emmetrope will quickly complain of discomfort.* Any refractionist can experimentally determine the same results on himself or others by the use of plus and minus lenses together with the use of prisms, base out and in. For the best reactions, the ocular conditions of any case with or without distant lenses should approach closely emmetropia and orthophoria.

Presbyopia, attended as it is by sclerosis of the crystalline lens, requiring more and more effort to obtain even a moderate amount of accommodation; or in the advent of the effort so required being too great for the correction of even a small or moderate degree of ametropia, which may result in complete suspension of the effort in the interest comfort, are all vital factors to be observed and noted in the complete analysis of the ocular condition relative to the source of discomfort.

There are of course great numbers of different quantities of the ametropias and the heterophorias found in each of the 14 principal classes of deranged ocular functions mentioned in the first page of this article. And while almost any case (non-pathological) might be cited to support the contentions made in this paper, it is not the purpose of the writer at this time to exhaustively treat the subject matter, but merely to call attention to points which he believes

vitally enter into the analysis of the source of discomfort, so that the refractionist can intelligently prescribe the lenticular, prismatic, or calisthenic aid to the end that comfort will take the place of discomfort.

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Oculo-Prism Treatment

How to Make Ocular Muscle Tests and Give Practical Muscle Exercises

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CHAPTER VI

Oculo-Prism Treatment—Practical

Administering Muscle Treatment by "Reverse Procedure" (Exercise Self-Administered)

IN connection with the practicability of muscle work it will be well to discuss an element of economy in practice, dealing with the time factor, which almost wholly eliminates friction in service, and loss in patronage, due to several patients gathering for treatment at the same time. The remedy lies in the ability to administer treatment to several patients simultaneously. In preparation for that type of service one thing becomes essential. Sufficient equipment must be provided to permit simultaneous treatment of as many patients as one's clientele warrants. Such equipment may be added from time to time, however, as an increasing practice will justify.

In order to administer treatment to several patients at one time, it must be possible to perform such work without giving undivided attention to an individual patient. In other words, no patient can be permitted to monopolize the operator's time or attention. This is accomplished by what the author terms exercise self-administered or the *reverse procedure*.

Ordinarily, in administering muscle treatment, the operator, standing beside his patient, gradually rotates increasing prismatic power before the eyes until a maximum pull on the muscles exercised is in force and diplopia develops. Immediately following, or after a short interval, the exercise is repeated and this continues throughout the treatment,

with possibly a few prolonged pauses or muscle tests intervening. It is obvious that applying treatment in this manner demands undivided attention on the part of the operator for each individual patient. On that basis, the complaint sometimes heard that muscle treatment monopolizes too much of the operator's time seems quite substantiated. But the system of muscle exercise by *reverse procedure*, applicable to single treatments as well as those in groups, completely solves the problem of time economy, and places the work upon so practical a basis as to safeguard the interests of the busiest refractionist.

As previously explained, exercising a muscle consists of exerting a pull on that muscle by subjecting it to the influence of gradually increasing prismatic power, from zero to that degree which represents the muscle's limit of endurance, at which diplopia takes place. If prismatic power be placed before the eyes while closed, then upon opening them, the eye muscles influenced by the prism will undergo the completely variable range of pull, as when submitted to gradually increasing power from zero to that of the prism before the eyes. In other words, the extrinsic muscles of an eye, which are affected when looking through a prism of given power, do not experience its full influence instantaneously upon application of the prism, but undergo a gradually increasing stimulation until the influence of the total amount of prism has been invoked. To further illustrate: If we assumed that for *every degree* of prismatic power applied to an eye there is stimulated a flow of *one unit* of nervous energy through the muscle influenced, a 5 degree prism would not develop an initial flow of 5 units of nervous energy. Instead, stimulation would be induced gradually, subject to that inertia which seems to characterize the initial application of all forces or energy. That is to say, stimulation and flow of energy would begin with the quantity *zero*, just as if zero prismatic power were first applied, and gradually increase in flow until innervation represented by the total amount of

prism applied (5 energy units for 5 degrees of prism) would be finally in force. This, of course, happens in what appears so short an interval as to justify the belief that the full force of the prism has become operative upon its application to the eye. The fact remains, nevertheless, that the stimulation is of a uniformly increasing character, from zero, the moment the eyes are opened, to the full power of the prism, a second or so later.

It thus becomes apparent that it is no longer necessary for the operator to remain beside his patient rotating prisms from the beginning to the conclusion of a treatment. On the contrary, it is just as efficacious to place before the eyes the maximum or nearly the maximum prismatic power which the eye muscles can withstand and instruct the patient to observe through these the letters upon the distant chart for a given period, after which the eyes are to remain closed for another period and the eyes to be thus consecutively opened and closed as directed, thereby self-administering the exercise.

In that manner an operator can conduct the treatment of five or more patients at one time if necessary, demanding of him nothing beyond his intelligent supervision. The manner in which the author conducts such treatments may prove useful and interesting.

Illustrating How Treatment is Applied to Two or More Patients Simultaneously

Messrs. A, B and C call for muscle treatment at approximately the same time. (It is assumed that sufficient equipment is at hand for conducting the several treatments simultaneously.) The patients are seated in their chairs; instruments are set or adjusted into position, and former records consulted. Mr. A.'s record shows that the internal muscles are under treatment and that a maximum adduction of 12 degrees had been reached at the preceding treatment. Accordingly, 12 degrees of prism, *apices in*, are

rotated in position and he is instructed to fix the small letters upon the distant chart.

Mr. A. reports diplopia, indicating that his adduction at that moment is less than 12 degrees. The prisms are quickly rotated to zero, and gradually increased in power, until at 10 degrees it is found that single binocular vision can just be maintained. With that amount of power permitted to remain before his eyes, he is instructed to continue looking at those letters, counting *ten* mentally, and to close his eyes for a period of *five*. He thus continues to open and close his eyes consecutively, for the intervals designated, and proceeds with this exercise until further instructed. During such exercise the patient is permitted to close his eyes for longer pauses or to shift his gaze upon other objects. This is for the purpose of relieving the monotony or avoiding exhaustion. The entire preparation and instruction as above outlined, will consume ordinarily about five to ten minutes.

Messrs. B. and C. are similarly instructed, after prisms had been arranged in accordance with the nature of their treatment, and the requirements suggested by cursory examination and preceding data. Thus in a period of approximately 15 to 30 minutes, three or more patients may be properly launched upon courses of muscle treatment. Should a patient desire the operator at any moment, a small bell at his side, or a colored electric bulb, operated by a push button, will invite attention. In the meantime, the operator may be engaged in limited conversation with other patients, or conducting a refractive test or examination. It is essential, of course, that the operator be ever on the alert, during such treatments, and provide the supervision necessary in the best interest of patients.

At intervals of about ten minutes, the operator visits A, B and C respectively. While again engaged with A, he learns, perhaps, that with the 10 degrees of prism, *apices in*, fusion is now accomplished readily and maintained without effort. Rotating 12 degrees into position, he finds single

binocular vision still maintains. With 14 degrees before the eyes, fusion continues, but with some difficulty. Sixteen degrees create a decided pull upon the muscles and a slight blurring of the letters, but single binocular vision is otherwise unimpaired. It is then deemed advisable to continue the treatment with 16 degrees before the eyes, and patient A is instructed to proceed with that exercise, while B and C are now visited in their turns. Their respective progress being noted, the proper prismatic power is rotated in position and the patients instructed to further continue their exercises. On the average, but five minutes to the patient should suffice at each inspection to determine the altered muscle status and to rotate into position that prismatic power necessary to properly continue the treatment.

In many cases it is possible to distinctly increase the duction from two to four times during a single treatment. This depends of course on individual responsiveness and the period devoted to exercise. It will generally be found upon measuring the duction at the beginning of each treatment that it is slightly less than the maximum attained at the preceding one. This is due to the fact that a portion of the duction registered while the eye muscles were repeatedly stimulated expresses an innervation which had not yet become permanent, and therefore subsides after the activating influence has been removed.

How to Handle the Individual Patient

Periodically, as time permits, and especially during the early exercises when the average patient is still dependent upon the operator's personal attention, it is well to remain beside him, rotating prisms, instead of initiating too early the method of *reverse procedure.* This necessity will vary with individual patients, but is always beneficial until the new patient's familiarity with the purpose of exercise and his changing experience have been well established. A better appreciation of service and a higher respect for the

efficacy of the treatment on the part of patients generally accompany the operator's personal participation in the work. This attitude is always conducive to most favorable results. The operator, too, will thus learn much which will facilitate his work, by studying personal traits and characteristics in each patient, discernible only under proper and sufficient observation.

In beginning an exercise, it has been the author's custom to converse slowly with his patient in a low, modulated tone, asking questions pertinent to the work and governing the operation of his prisms in accordance with the patient's replies. Such conversation becomes, in fact, a part of the procedure and with proper poise and modulation should never be disconcerting, but prove instead a guide in leading to correct answers and in securing for the operator the necessary information to better prosecute the work.

Beginning a treatment, the operator may address his patient as follows: "The instrument I am placing before your eyes will exert no influence to begin with, so relax, please, and look through it at those small letters upon the distant chart. Do they seem plain to you? Very well, then. Now continue to look at them but do not stare or otherwise exert yourself. In fact, Mr. ———, I believe I would relax a little more. That's right. Are you sitting comfortably? Now that's better!" The operator is now ready to begin rotating prismatic power before the eyes. He then continues:—"Now, Mr. ———, as I begin operating this instrument kindly tell me when the letters become slightly blurred." After a pause, he continues, "And also tell me, please, if you experience a slight pull or drawing sensation about the eyes. And should you suddenly perceive two charts or two sets of letters in place of one, please advise me immediately." During the latter discourse the operator has begun *slowly* to rotate prisms *apices inwardly* or *outwardly*, depending upon whether the internal or external muscles are to be exercised. While thus rotating

prisms, the operator continues questioning in a low modulated tone. "Are you feeling any pull upon the eyes yet? How do those letters appear? Are they still clear? You do feel a slight pull now? And the letters you say are doubled now? Oh! they are together again? Very well, then. Now continue looking at those letters, please, and as soon as they break up again, but remain separated, inform me." Immediately upon being informed that the letters have broken up into two sets of letters, the operator must cease rotating prisms, inasmuch as diplopia is then in force and the limit of duction had been reached.

Should the patient declare that images have re-united, after reporting diplopia, it is evident that the muscles have received innervational reinforcement in order to have affected the re-establishment of single binocular vision. During the period that maximum prismatic power is permitted to remain before the patient's eyes, diplopia and single binocular vision may alternately take place several times. In that event, the muscles are manifestly undergoing strenuous exercise. It is more than probable, however, that when diplopia once occurs, the new patient, particularly, will of his own accord be unable to fuse the images without some assistance from the operator. The operator, therefore, should ever be watchful and when, after several seconds, diplopia seems established, he should rotate prisms back to zero and thereby assist his patient in regaining single binocular vision. Thus treatment continues, and the exercise as formerly described is successively repeated. Should the patient report that the letters are becoming blurred, it is the first evidence that they are overlapping, that diplopia in a more pronounced degree is about to ensue, and that the limit of duction is being reached. The operator *may* even then cease increasing prismatic power, permitting that amount of power to remain before the eyes until a definite diplopia takes place, or rotate back to zero, in advance, and renew the exercise.

Persistent Exercise

Occasionally, an operator may sound a patient's ability to voluntarily overcome diplopia, by urging him to persist in the attempt to re-establish single binocular vision, with that prismatic power before the eyes which is just sufficient to create diplopia. In imposing such strenuous efforts, good judgment, however, must be exercised. Experience will teach the operator when such an attempt is fruitless; the prisms should then be quickly reduced in order to assist in re-establishing single binocular vision. Some of the most stubborn cases, resisting all other methods or efforts at innervational stimulation, have often responded to sheer persistence under the method above described.

Reflex Disturbances Due to Exercise

Physical disturbances due to exercise have but on rare occasions appeared conspicuous to the author in his practice. A patient, who is anaemic or of low nervous equilibrium, may occasionally, when subjected to persistent treatment, show signs of a nervous reaction. Such experiences are unusual, however, and offer no cause for apprehension. Proper care and solicitude, though, should always be exercised when ministering to the physical welfare of an individual.

CHAPTER VII

Oculo-Prism Practice

IN the study of oculo-prism practice, we shall not engage in an analysis of the functions involved in the process of muscular exercise as much as we shall deal with the manifest responses made evident under such exercise as shown by the changes wrought in the duction powers or convergenal reserves.

We are not concerned here with the subtle theories underlying innervations but feel interested rather in the practical

results that may be attained, thus coördinating and substantiating by experimental proof such relationships as may seem to exist between innervational deficiencies in extraocular muscles, an asthenopia which may then exist, and the elimination of such discomfort as made apparent by a changing innervation developed through muscular exercise.

We hope we shall not be accused of being unscientific in the pursuit of a practice, largely empirical as yet, but sustained by self-evident conclusions, though we may still lack a positive basis upon which to minutely explain the phenomena that take place. As refractionists, however, we find special benefit in an intimate knowledge of the grosser but more practical elements involved in a course of muscular treatment, and to such endeavor we may lend ourselves unstintingly, with the assured hope that a due measure of success will attend our efforts. With this thought before us we may proceed profitably with an analysis of the technique involved in the administration of oculo-prism treatment.

Two Types of Oculo-Prism Treatment

As already indicated in other portions of this treatise, muscle-exercise may be administered in more than one way. Broadly speaking, it may be divided into two types: First, that by which an increasing prismatic influence is maintained by the operator's personal participation throughout the treatment—*i. e.*, while the patient looks steadily at a fixed type, the operator rotates his prism with gradually increasing power until diplopia ensues, after which the prismatic power is quickly reduced to zero and the former process successively repeated; second, that method which has already been designated as "treatment self-administered." Here practically no participation of the operator becomes necessary beyond a surveillance of the case, with changes in prismatic power before the patient's eyes instituted as a development or change in the duction powers takes place.

How this latter method of administering treatment to several patients simultaneously may be pursued efficiently has already been discussed in former paragraphs.

Coöperation between Patient and Practitioner

In all cases it will be found advisable to administer, in the beginning, at least, the first type of exercise to the patient —that is, until such time as he has learned to dominate his innervational impulses and seems familiar with the nature and purposes of the treatment. While it may ordinarily seem better, for psychological reasons, to keep the patient ignorant of the exact character and purpose of the treatment, it has been the writer's experience, that, inasmuch as intelligent coöperation on the part of the patient is most essential and often indispensable to successful results, it is well to take the patient into the operator's confidence, and by a brief but clear and forceful analysis of the case arouse his interest and enlist his coöperation. The intelligent patient is averse to mystery in connection with his (or her) ailment. He is trained to think concretely and expects the professional man whom he consults to be skilled in diagnosis, and to be capable of "picking to pieces" the salient characteristics of his case, outlining his procedure with reasons for its employment. After some such understanding has been established between patient and operator, the latter must then utilize every agent within his means to demonstrate his correctness and help guide his patient so that coöperation will be directed into proper channels, and the fruit of united efforts may quickly be realized. Every practitioner knows how disconcerting are the marks of stupidity evinced by some patients. In no branch of refractive work is the danger from misunderstanding greater than in ocular muscle work. The operator here must be guided wholly by subjective testimony, and unless a reasonable comprehension of the work is placed within reach of the patient, no end of grief and disappointment may be anticipated. It is only by

close contact between patient and operator—during the first few treatments especially—that difficulties will be eliminated and a clear path laid for a successful course of treatment.

Behavior of the Maddox Rod

As the operator establishes a coöperative relationship between himself and his patient, he will be apprised by the latter of numerous sources of confusion which otherwise lead to erroneous testimony and subsequently defeat his efforts or make his work most trying and arduous. Nor will the examiner always understand the complaint presented unless he has studied his instruments and equipment, and has learned for himself the secondary optical effects often created by his appliances and the tendency which these have to divert the patient's attention and impeach his testimony.

An illustration of such behavior is the effect of the multiple Maddox rod before the eye of the average patient. While the test involving the use of the Maddox rod is not strictly comprehended under the work of muscular exercise, its use seems to be an almost indispensable preliminary step, and bears discussing in connection with this work. It is not at all unusual to hear a patient state that he sees several streaks instead of one when attention is called to the image observed by the eye before which is placed the Maddox rod. Such multiple streaks frequently exist when working with a mirror in a ten-foot space—to provide the conventional 20-foot distance—and are the result of double reflections, or minute sources of light from other channels. If such associated streaks have sufficient luminous intensity, the patient may vary his testimony in accordance with whatever streak he happens to be fixing at the time.

To forestall such occurrences the writer generally questions his patient in advance as to the number of streaks that are visible, and then emphasizes the fact that only the brightest one of these shall be considered and that the others be totally

ignored. A seemingly complex and disturbing element is thus often eliminated and a confidence and rapidity maintained most essential to a successful termination of the work.

Behavior of Excessive Prismatic Power before the Eye

Another evidence of the value of keeping closely in touch with the patient, in his early treatments, is to be found in the fact that a diplopia may occur of which he is entirely ignorant. The patient will continue to fix with one eye, declaring that no pull is experienced, while the operator unduly congratulates himself upon the marked progress made only to find himself baffled and disillusioned in a subsequent test or treatment. Not alone is this likely to occur when the operator is not attentively on the case, but the same experience will be recorded among practitioners who are giving their patient uninterrupted attention during an entire treatment, but have not been sufficiently alert or are not sufficiently competent to recognize a sudden diplopia as it takes place, while the patient himself is unconscious of the occurrence or for other reasons fails to apprise the operator of the fact. This situation will arise in those cases in which the quantity of prismatic power, before the patient's eyes, is in excess of the prevailing duction power at that moment, but which can be held periodically under stress and excitation due to zeal and special effort. *It is a good point to remember that when the patient accepts increasing prismatic power with apparently no effort, and the prismatic quantity is beginning to run high, that a state of unconscious diplopia is possibly in force, and a slow and careful re-survey of the duction should be made to ascertain definitely the true condition of the prevailing duction.* Sudden diplopia may develop not only when the prismatic power before the eyes exceeds the normal ability of the muscles to maintain single binocular vision, but in irregular states of innervation as well, and as indicated under the heading of "periodic diplopia."

How to Develop Technique in Oculo-Prism Work

Perhaps nothing that has been said heretofore should command the attention of the prospective operator in the field of ocular muscle treatment as much as the technique involved in the successful pursuit of this work. Under the above heading alone may be classified every step which can be delineated in this chapter, although subdivisions and captions will be found useful to stress the special points to be indicated. Considerably less can be said of the process of exercise which is self-administered than of that which may be related in connection with exercise assiduously applied by the operator throughout the full period of treatment. It is during this type of exercise that everything which is essential, both to an understanding of the case and detail in procedure, is made available. Here will be found the crux to one's capabilities as an administrator of ocular prismatic treatment, and it is here that the willing student must set his stakes in an endeavor to master, as far as is possible, the delicate points involved in oculo-prism practice.

Regarding Sources of Innervations

Considerable has been written and said, from time to time, about innervational impulses. It is not the province of this work to analyze or dissect this factor of our work, but to refer to it only as practical demands make necessary. We have been told that over the converging faculty presides, broadly speaking, two types of innervation,—that which is coördinated with *accommodation*, and that due to the *fusion* sense, which by some is designated as a sort of psychic phenomenon. We have also been taught to segregate impairment of the fusion faculty from that of plain convergence (associated with accommodation), and that the fusion sense may be stimulated or developed, when deficient, by a process of exercise through the use of the amblyoscope or some similar device designed for that purpose.

In the treatment of deficient innervations in the ocular muscles by prismatic exercise, as presented by the author, no differentiation is made as to primary sources of innervation. Two facts stand out preëminent in any consideration we may give the subject. First: innervations to the extrinsic ocular muscles—wherever their source—can be reached and influenced directly, so far as we know today, only by the application of prisms as a palliative or stimulative agent, and this can be accomplished through the common modes herein and elsewhere described. Second: any application of prismatic influence must be pursued under conditions that harmonize with those to which the eyes are ordinarily subjected. That is to say: it would seem illogical to test the muscular status (duction) of an eye while undergoing one kind of function (*e.g.*, staring blankly into space), and with the deficiency corrected under such fixation and data, hope to insure muscular comfort under such efforts as are, for instance, required to read fine print for prolonged periods, or to perform intricate needle work at the usual distance.

In other words, if the operator will learn to treat his case under the very conditions which create the complaint, he will need to worry little about the source of disturbance—whether it be purely lack of convergence or weakness of the fusion stimuli. This point it is well to bear in mind, for it eliminates undue speculation on the part of the beginner especially, and when reaction to muscular exercise seems negative, he need not chide himself for inefficiency or inability to differentiate between various types of defective innervation which, perhaps, if better understood, could be subjugated under selective forms of muscular treatment. Such a state of efficiency may at some future time be reached. For the present, however, we shall not worry about it, and each may hope to attain reasonable success by administering the one available agent—prismatic influence—to defective innervations, made apparent through subnormal duction powers or reserves and an asthenopia which is often the

incentive to an investigation of the innervational status of the extrinsic ocular muscles.

Illustrative Case

A case which will help illustrate the point under discussion is the following: Mr. C. is a man about 55 years of age. He holds a position with a railroad company where his duties are both exacting and manifold. He spends an hour or more each morning looking over his mail. After that he spends another hour or so making close inspection of certain machinery and work. In the afternoon, he generally engages in more or less delicate repair work, which, it seems, he alone can do. The remainder of the day is spent at miscellaneous duties which require near use of his eyes, and always with special concentration. In fact, he uses his eyes so uninterruptedly throughout the day at near work, that he almost constantly wears his reading glasses. He has not yet felt inclined to use bifocals. His complaints are a tendency for print to blur, at the reading distance; a strange uncomfortable pressure through the region of the upper lids, in both eyes; a periodic vertigo due, it is surmised, to an auditory disturbance for which he had taken treatment without success. Others had recently examined his eyes and advised that there was nothing which could be done to correct his ocular complaints.

When the writer examined this patient, he found a distant error of O. U. +0.50 to +0.75 D. S. A total of O. U. +3.00 D. S. for near work left him, monocularly, a near point of about 7 to 8 inches, evidently affording a satisfactory accommodative reserve. This latter prescription he was already wearing in his working glasses. From a refractive standpoint a change in lenses did not seem advisable, and it is for this reason, perhaps, that his previous examiner felt unable to assure relief through refractive correction.

Upon investigating his muscular status, there appeared a distant esophoria of 1 degree. At the reading distance,

however, an exophoria of about 16 degrees was evident. Adduction measured 8 degrees, and abduction about 6 to 7 degrees. The positive convergenal reserve (adduction at the reading distance) was 8 degrees and the negative convergenal reserve (abduction at the reading distance) about 12 degrees. The vertical muscles appeared to offer no disturbing factors.

Of the several complaints indicated, the pressure about the eyes and a blur in the left eye appeared the most intolerable. The writer administered several muscular treatments with fixation at 6 meters distance, but the patient felt conscious of no change in symptoms nor was a marked increase in adduction to be noted. It is worth stating that persons in advanced states of presbyopia do not respond to muscle treatment as readily as younger persons, for the possible reason that the extrinsic muscles undergo an impairment due to advancing years quite similar to that experienced by the ciliary structure. To those up to the age of 60, however, the writer has never been deterred from giving prismatic treatment, and in many such instances has experienced conspicuous success. In fact it appears that presbyopic cases are those particularly in need of such treatment.

In the case of the patient under discussion, several treatments with fixation at 6 meters had as yet offered no encouragement. The patient, inclined to be pessimistic, was ready to abandon further treatments, nor was the writer certain of success—in view of the complication in symptoms—beyond the fact that defective innervation was indicated, and, as one step at least in the interest of nerve conservation and economy, a normal state of relative ductions should be sought and established.

It is a trying situation to be confronted with a case which has much to offer in the way of practical unfoldment, upon the pursuit of which, however, one's satisfaction is likely to suffer should results prove unfavorable. The uncertainty of achieving wholly satisfactory results through prismatic

exercise in the face of a host of derangements is not to be minimized. There is one element of security, however, to which the practitioner, reaching out more or less blindly in the interests of his patient, may safely anchor. *Compare the nature of the ocular distress or pain emphasized by your patient, and from which he is seeking relief, with the stress or pain developed during or through the ocular exercise.* Invariably, if your exercise is reaching the seat of trouble, the patient will advise you that his chief disturbance seems aggravated. Or, perhaps, he may state it as follows: "Do you know that if I look through this instrument at those letters, I feel the very pain that I have been telling you about?" And, should you ask him if the discomfort is as great or greater than usually experienced the reply will be, as a rule, "greater." Far from feeling discouraged over such testimony, one may rest assured that he is working in the right direction.

So it was with the case we have under discussion. With treatment at 6 meters distance, no progress seemed apparent after several exercises. Adduction had been increased but slightly; the patient experienced the same degree of ocular tension that had formerly annoyed him; and in reply to my questions concerning his ocular sensation under exercise, could not state definitely if it resembled the peculiar strain he felt when engaged in his daily vocation.

Then the following thoughts came to the writer: In exercising the patient's extrinsic ocular muscles, with fixation at a distance, treatment was not being instituted under the prevailing conditions during which pain or discomfort was experienced. This man is using his eyes almost constantly at a reading or working distance, at which times he is conscious of ocular strain and disturbance. Furthermore, the relation between adduction and abduction at 6 meters and the same or similar forces at the working distance show a considerable discrepancy as shown by the ratio of 8 degrees adduction to 6 or 7 degrees abduction at 6 meters as against

8 degrees adduction and 12 degrees abduction at the reading distance. Furthermore, it should be noted that the patient's complaint did not seem to be present in distant vision (the writer made a point to investigate this) but was confined wholly to periods during which near-vision was in force.

Treatment was then continued with fixation at a small reading chart held at 13 to 14 inches from the patient. After the following treatment the patient complained of slightly increased vertigo. Another treatment elicited the information that the pressure in the region of the eyelids seemed quite marked. In the meantime, adduction, or the positive convergenal reserve, increased to about 14 to 16 degrees. During subsequent treatments the patient made continued reference to the similarity in discomfort between that experienced while using his eyes at near work and that developed during exercise. The latter discomfort he declared to be the more violent. Each day, as he came under prismatic exercise, there was evidence of an increase in the adduction. Quite recently, the positive convergenal reserve (adduction at the reading distance) has been raised from the condition of 8 degrees, when treatment was instituted, to 32 degrees, and this moreover in a man well along towards the age of sixty.

More recently he has confided the statement that the blur in his left eye is disappearing, that his vertigo is diminishing, that he is scarcely conscious of his former ocular discomfort, and stranger than all else is the fact that his hearing, for which he had sought treatment in vain, is definitely improving. Success in this case has been made possible not because of an ability to localize the primary source of disturbing innervation—although a more intricate analysis and differentiation of such factors is much to be desired and is hopefully to be anticipated as science progresses—but rather to the common-sense suggestion that, under whatsoever circumstances a function exhibits difficulty in carrying out

the demands made upon it, under just such conditions would it seem advisable to institute remedial application.

Dominating Innervational Impulses

A considerable portion of the proper technique in oculo-prism work will be found to lie in the ability to instruct the patient how to perceive and dominate those impulses, the development of which is so instrumental to the attainment of a state of muscular comfort. The operator himself must know what the patient should experience when subjected to prismatic influence in order to administer his treatments intelligently and successfully. Perhaps the first consideration to be given is the training of patients to make the necessary effort to harness or dominate the muscular impulses. When the patient has learned to control these forces, a decisive step forward will have been taken in the direction of desired alleviation. As to what is meant by mastering the innervations, will easily be grasped if the practitioner will subject himself to the influence of increasing prismatic power until a state bordering upon diplopia has been attained. The peculiar effort he must make to maintain single binocular vision, or the struggle he experiences in seeing singly, is the evidence of an effort to dominate the innervations which are being called upon to supply the nervous energy necessary to hold the eyes turned in the position essential to preserve single binocular vision.

In beginning a muscle treatment, the author instructs his patient as follows: "You will please select a letter or word upon this chart, and hold your attention upon it. As I operate this instrument continue to look at the same letter or word without shifting your gaze or attention. If you begin to experience a pull upon your eyes please advise me." As soon as the patient advises the operator that he is beginning to experience such a pull, it behooves the operator to proceed very slowly and cautiously in the handling of

his prisms. Sometimes the author ceases increasing prismatic power, but permits the patient to continue his gaze under the prismatic power then in force. The muscles are then ordinarily receiving all the stimulation which it is best to excite for the moment. Always guard against unconscious diplopia. With an increase in prismatic power, the patient may declare that the type is beginning to blur. Such a patient is already showing a mastery over his innervational impulses. The statement that the type is beginning to blur is an evidence that the patient is drawing upon his innervations to their fullest capacity at the then existent state of development, and that by marked effort—consciously or unconsciously—the innervations are defeating diplopia to the extent of permitting the minimum degree (of diplopia) to prevail as evidenced by a slight overlapping of images or blur.

Usually the patient's ability to maintain single binocular vision will collapse at or about this point, and a state of complete diplopia will be ushered in. Two letters or two words or two charts will then be made evident. There is then presented the first opportunity to test as to how well the patient is succeeding in dominating his innervational resources. When advised by the operator to make some effort to fuse the two letters or words into one, the patient will be observed to squint and frown and otherwise distort his face in the attempt to draw upon his innervational impulses. This outward manifestation is ordinarily an indication of an attempted fusion. Whether or not the patient is successful in his efforts will soon be determined by the statement that he again beholds a single image, or by the confession that images are still divided with no seeming possibility of ever being re-united again.

The operator must then quickly reduce prismatic power to zero or to such an amount as will permit the reëstablishment of single binocular vision, after which any power remaining before the eyes, with single binocular vision again

intact, will once more be operative upon the innervational impulses and the process of prismatic treatment will again be in operation. Prismatic power may then be gradually increased until former symptoms are repeated, and thus the process of educating the innervational forces to assert themselves is continued and enlarged and stressed until quantities of prismatic power, which formerly seemed hard to overcome, are easily maintained, with the subsequent result that the duction power becomes higher and a state of great ocular comfort becomes eventually manifest.

Importance of Periods of Rest During Exercise

We have so far been discussing the type of muscular treatment wherein exercise is being administered by the operator throughout the treatment. The patient in this case is not self-administering his treatment by looking at a fixation letter or word for several moments after which he closes his eyes for a corresponding period as instructed by the operator, only to reopen them and again subject them to the influence of the prisms. This latter method will be further discussed in succeeding paragraphs.

In the type of exercise now under discussion, the attention of the patient is maintained upon a fixation word or letter throughout the treatment. It is easy to appreciate how readily the eye may be unduly fatigued under such a process. The purpose of the exercise, in such an event, suffers if it is not wholly defeated. It is important, therefore, that the patient be permitted to rest his eyes periodically. The salutary effect of such rest (say two to three minutes) upon the developing impulses will be most encouraging as gathered from the increased duction which generally follows in a subsequent test.

Breaking Up a Resistance to Stimulation

That the operator need not become readily discouraged when meeting with unfavorable response is proven by virtue

of the fact that many cases which do not show a tendency to respond to prismatic treatment under ordinary procedure will often capitulate under duress of persistent and methodical exercise. The "cramp" in the duction, which may have previously indicated a tendency to vacillate between certain low degrees, without offering promise of any further development, will often, after a certain amount of intensive stimulation, appear to "break" and thereafter begin to climb quite rapidly and consistently until a normal or desired state of innervation has been attained. It is well to bear this in mind, for many times failure can be turned to success through the knowledge of the fact that a strong resistance to stimulation may be responsible for the negative reaction and that renewed efforts under persistent and well regulated exercise may achieve the desired end.

When to Apply Intensive Exercise

It is always advisable to initiate prismatic treatment gently, slowly and cautiously. The eye muscles are quite unlike the biceps, for example, inasmuch as they are much smaller, more delicate in structure, and more finely tuned and adjusted in relation to their needs.

While muscle treatment, when first administered, should be slow and cautious, it may gradually be intensified, but never without due regard for the individual characteristics of each patient. The writer in his practice has had occasion to build up an abduction in one case from a negative balance of 8 degrees (*i. e.*, it required 8 degrees, apex in, to permit distant fusion), to a normal state of 8 degrees, making a total of 16 degrees of abductive power developed. This was accomplished with no apparent discomfort to the patient. Yet, in another instance, a young woman undergoing muscular treatment with a total of but 4 degrees of prism, apex out, before her eyes, swooned in her chair and was resuscitated after several minutes of unconsciousness. While

extreme occurrences of this type are rare, they are not to be ignored entirely and one should so engage in this work as to make ample reservation for like contingencies.

As to when the operator may safely and consistently administer a more strenuous form of exercise will best be answered by the circumstances of the case and an intuition which gradually develops as one engages in a more active practice of oculo-prism treatment. There are but few times when the author has hesitated to administer a more persistent form of treatment. As a rule, the patient should have received at least two or three periods of exercise of not too strenuous a character and should show a knack of handling or controlling his innervational impulses before more strenuous efforts should be imposed upon him. The more strenuous forms of treatment need not necessarily be confined to such cases as show a "resistance" to any stimulation. On the contrary, those cases which respond readily to muscular exercise will of necessity be given higher increments of prismatic stimulation, in order to keep pace with the ability of those eye muscles to "take on" rapidly the effects of such stimulation. However, to such patients the exercise may appear quite normal, and an intensive or "forced" exercise becomes more or less of a relative term.

How to Administer Intensive Exercise

Any differentiation which may be indicated between "ordinary" and "intensive" exercise lies in the frequency of separate stimulations and the degree of prismatic power under which stimulations are inaugurated. An intensive exercise becomes utterly impotent when the prisms before the eyes exceed the power of fusion. In other words, unless the eye muscles are maintaining binocular single vision under the prismatic stress, or are on the verge of establishing or striving to establish binocular single vision (as is evidenced by the images alternately coming together

and separating), the influence of the prism cannot be operative and prismatic treatment is really not in force.

Giving intensive prismatic exercise implies, therefore, that the operator must continuously and persistently (with such pauses as are essential to prevent collapse or fatigue of the eye muscles) apply variable stimulation—from zero to the highest degree of prismatic power with which single binocular vision can be maintained—such cycles of stimulation to be repeated again and again (with short pauses intervening) until gradually a higher muscular tonus is made evident and a higher permanent duction power has been established.

While ordinary exercise is administered in very much the same way, the difference lies in the fact that, in the intensive form, the operator applies himself more diligently to the task before him, is ever striving to make his patient overcome and hold more and more prismatic power, and is encouraging his patient almost to the point of coercion to accept a steadily growing prismatic power while yet maintaining single binocular vision. During such a process, diplopia may occur again and again. At such times the operator must quickly reëstablish single binocular vision by rotating his prisms back to zero or to a point at which his patient can fuse the letters, after which he begins a new cycle of stimulation by again rotating the prisms in ever increasing power, until diplopia, perchance, again takes place, or better yet until the patient advises him that the strain seems about all he can hold and that the letters seem blurred or have a tendency to "break." At such moments the stimulation is at its height, and it is at such periods that the author has often left the patient to struggle for several moments with the prismatic power before his eyes—with the subsequent report, generally, that the letters are becoming clear and that the effort to fix the letters is becoming less difficult, added to which is the fact that an extra degree or two of prism can now be overcome. Such is concrete proof that innervational reinforcement has been found available to meet the onslaught of prismatic force.

Direct and Indirect Methods in Oculo-Prism Work

In that which has gone before, we have dealt specifically with that type of treatment in which the operator remains beside his patient continuously, operating the prisms throughout their cycles of increasing and decreasing prismatic power, while the patient maintains a steady fixation during treatment. The patient's attention must be given periodic rests, as an uninterrupted stare will cause extreme fatigue, lachrymation and other disturbances which will prove detrimental to the work. This method of exercise may be termed the *direct method*.

In the major portion of oculo-prism work, however, the type of exercise administered is that which has been denominated by the author as "reverse procedure" or "treatment self-administered." The advantage of this latter method is two-fold—neither the operator nor patient become readily fatigued, and treatments may be administered to several patients simultaneously, thus providing a more desirable system from the standpoint of both physical and practical economy. This method may be properly denominated the *indirect method*. While it is recommended that the first two or three treatments be administered under the first or *direct method*, it becomes almost imperative to resort to the latter form of treatment, *i. e.*, the *indirect method*, for the remainder or major portion of the exercises.

Indirect Method Described

In a former chapter this process of treatment by "reverse procedure" has already been somewhat elucidated. Should the applicability of the name designated seem uncertain to the reader, it may be stated that the indirect method is indeed one of "reverse procedure" and one in which the treatment is necessarily "self-administered."

The principal involved is based on the assumption that an eye looking through a prism is stimulated progressively

from zero prismatic power, at the moment the eye looks through the prism, to the full amount of the prism's power after a second or a fraction of a second of fixation—depending upon how quickly the innervational centers respond to the total prismatic influence of the prism. An eye, therefore, when looking through a prism is stimulated in a rapidly progressive manner—from zero to the full power of the prism—which maximum stimulation then continues in force until the prism be removed or the eye can no longer withstand the action, giving rise perhaps to a state of diplopia.

It is not necessary, however, that the prism be removed from before the eye in order to terminate its influence. Upon closing the eyes, they quickly assume a position of rest, which is perhaps more complete and pronounced than if they were permitted to remain open with no prisms before them. In fact a much better relaxation is thus afforded, and the author has utilized such a process for this as well as for another reason. Not alone do the eyes experience a refreshing rest after being closed several seconds, but upon reopening they find the prisms already in position and quickly undergo another cycle of stimulation from zero to the power of the prism; and so, intermittently, a series of stimulations and relaxations become available with no more effort than is required to alternately open and close one's eyes. With the maximum of prismatic power, under which an operator may feel justified in the administration of any portion of an exercise, he needs but rotate into position the desired prismatic power and instruct his patient to fix a letter or word through those prisms for a period of say 10 seconds, and to then close the eyes for an equal, a greater, or lesser period (as the case may warrant). The patient is then further instructed to alternately open and close his eyes for such periods as indicated and he may thus continue to self-exercise his extrinsic muscles without further assistance from the operator. Thus the ocular muscles undergo successive stimulation and relaxation under a process

which is the most convenient to both the patient and operator, and which undoubtedly affords a most efficacious exercise. It may be designated as a process of "reverse procedure," because it is quite the reverse of the *direct method*. In this latter method the prisms remain before the eyes with power unchanged throughout any specified portion of an exercise. The eyes, upon being opened, undergo influences similar to those experienced under a steadily increasing prismatic power, just as though the prisms had been gradually increased in accord with the rising stimulation. In other words, the prisms remain unchanged in power, while the eyes must open and close in order to procure a variable stimulation. In the direct method, on the other hand, the eyes are kept open and fixed, while at the same time the prisms are made to vary in power in accordance with the desired stimulation. It is quite obvious that one process is the reverse of the other. It is also obvious that by the indirect method the treatment is self-administered.

Innervations at the Reading Distance

It is highly important that the operator form the habit of carefully measuring the state of balance and duction powers at the reading distance. This is particularly important in the case of persons well advanced in the presbyopic age. The behavior of the adductive powers at the reading distance may in such cases be compared to that of impairment of the accommodation. A deficiency in innervations due, perhaps, to structural changes in the converging muscles is probably the disturbing factor. Such cases almost invariably demand prismatic exercise at the reading distance, particularly if a substantially high degree of hypermetropia coëxists. Suggestive data in such cases will be as follows:

Distance imbalance,	1 or 2 degrees esophoria to 1 or 2 degrees exophoria.
Distance adduction,	8 to 24 degrees.
Distance abduction,	4 to 10 degrees.

Imbalance at reading distance, Orthophoria up to 10 or more degrees exophoria.
Adduction at reading distance, 6 to 20 degrees (positive reserve).
Abduction at reading distance, 4 to 20 degrees (negative reserve).

By a comparison of the above data, one will note a strong tendency for the distance imbalance to change from an esophoria or orthophoria to that of an exophoria at the reading distance. One will also note that the reading and distance adduction do not undergo the same relative change that the near and distance abduction experience. Adduction at the reading distance will be increased but slightly, if at all, over the corresponding distance power. It may, in fact, show a tendency to decrease at the reading distance. Abduction, on the other hand, seldom decreases at the reading distance. Its tendency towards increased power at that distance is conspicuous. The numerical basis, therefore, upon which the altered muscular balances between far and near may be roughly estimated can be computed from the altered character of innervations expressed in duction power at the reading and distant points.

A concrete example is that of Mr. C., age 55.

1 Distance imbalance, 1 degree esophoria.
2 Reading imbalance, 16 degrees exophoria.
3 Distance adduction, 8 to 10 degrees.
4 Reading adduction, 12 degrees.
5 Distance abduction, 6 to 7 degrees.
6 Reading abduction, 16 to 18 degrees.

If we compare the ratio of (3) to (5) with that of (4) to (6), it becomes easy to comprehend the altered balance made manifest between (1) and (2).

Another concrete example is that of Mrs. M., age 57.

1 Distance imbalance, 1 degree exophoria.
2 Reading imbalance, 16 degrees exophoria.
3 Distance adduction, 24 to 28 degrees.
4 Reading adduction, 12 to 16 degrees.
5 Distance abduction, 10 to 12 degrees.
6 Reading abduction, 28 to 30 degrees.

If we again compare the ratio of (3) to (5) with that of (4) to (6), we shall readily understand the change in muscular balance as represented by (1) and (2).

As emphasized in former paragraphs, it is not the aim here to analyze the functional laws by which duction powers are determined, but to recognize their state and administer to their needs in the light of practical necessity. With that thought before us, we are led to give heed to innervations at the reading distance, primarily, as indicated by the state of muscular balance but particularly as expressed by the *convergenal reserves*. With that phase of muscular work properly covered, the practitioner is not likely to have overlooked a formidable source of error, and can look forward with reasonable assurance to a state of muscular comfort and repose. It is well to remember that muscular exercise should always be initiated with corrections before the eyes, which are suited for the distance at which the treatment is being administered.

Prescott, Arizona.

[To be continued]

Abstracts and Reviews

The Interocular Distance

James Weir French, D.Sc.

THE writer reports upon his investigations made on the interpupillary distances of some four hundred persons of ages varying from 15 to 50 years. For the measurements of these distances he used a small Zeiss type of pupillometer.

Curve A of Fig. 1 shows the results obtained with men of 18 years and over. The interocular distances in millimeters are the abscissae and ordinates the number of men

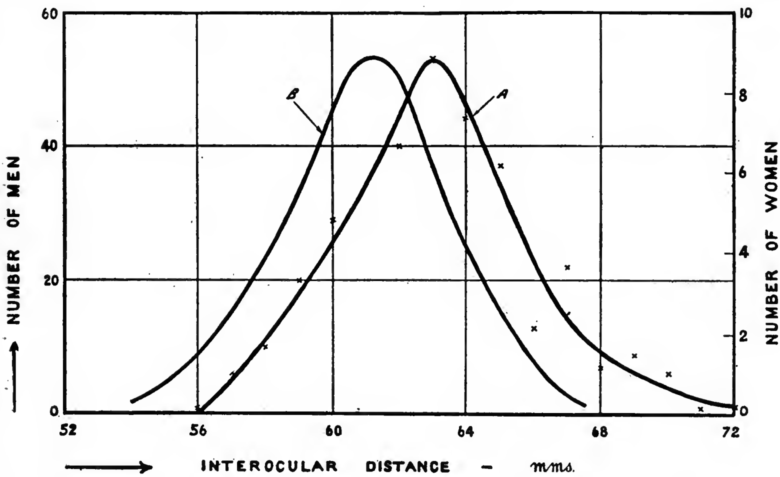

Fig. 1.

possessing any specified interocular distance. The mean value is 63 mm. Curve B is the plot of the results obtained from 50 women. The character of this curve is similar to

curve A. The whole of this curve is, however, displaced toward the left or the region of smaller interpupillary distances. The maximum ordinate also bisects the area contained within the curve and the mean value is at 61 mm.

Fig. 2 shows that the average interocular distance does not possess any definite change with age. In general, it

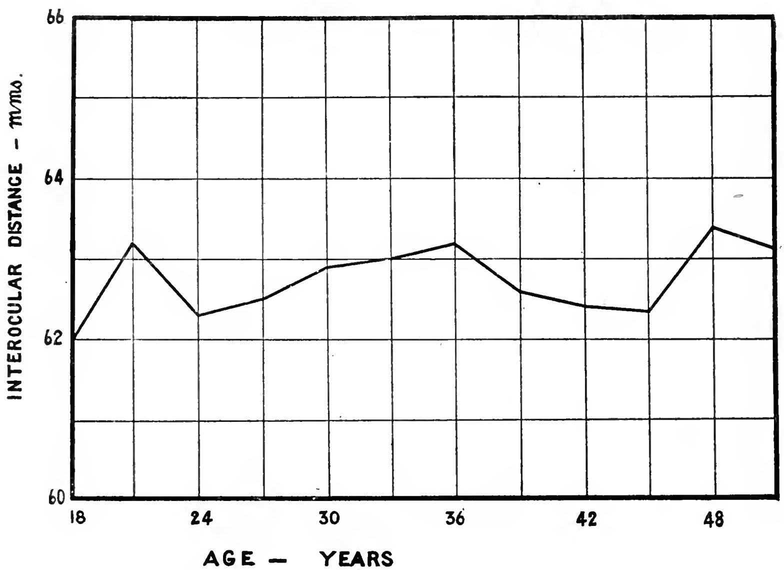

Fig. 2.

appears that the average value does not appreciably alter after the seventeenth or eighteenth year.

Fig. 3 shows the variation of the width of the head measured just over the ears in relation to the interocular distance. Abscissae represent interocular distances in millimeters and ordinates the average widths of head of the individuals included in each interocular group. At the lower separation there is a greater proportional increase of the width of the head which tends towards a maximum value

somewhat below 160 mm. Thus the larger interocular distances generally result from the eyes being set nearer the sides of the face rather than from a proportional increase of

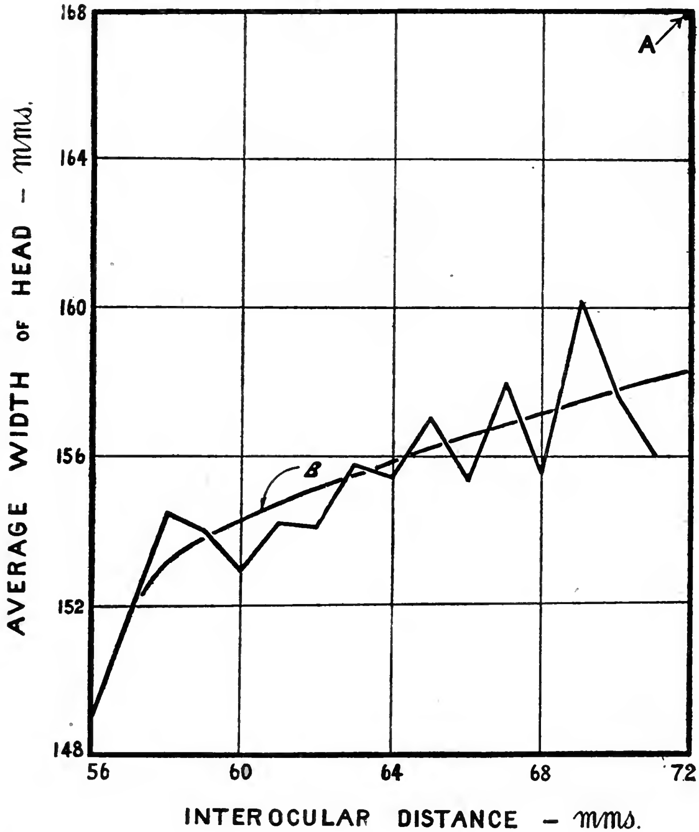

Fig. 3.

the lateral dimensions of the head and associated parts.

That there may be very abnormal cases is evident from the point *A*. It represents an individual having a head

168 mm. wide with an interocular distance of 72 mm., whereas, according to the curve, this interocular distance should correspond with a head of about 10 mm. less width.

As is to be expected, there is a fairly definite relationship

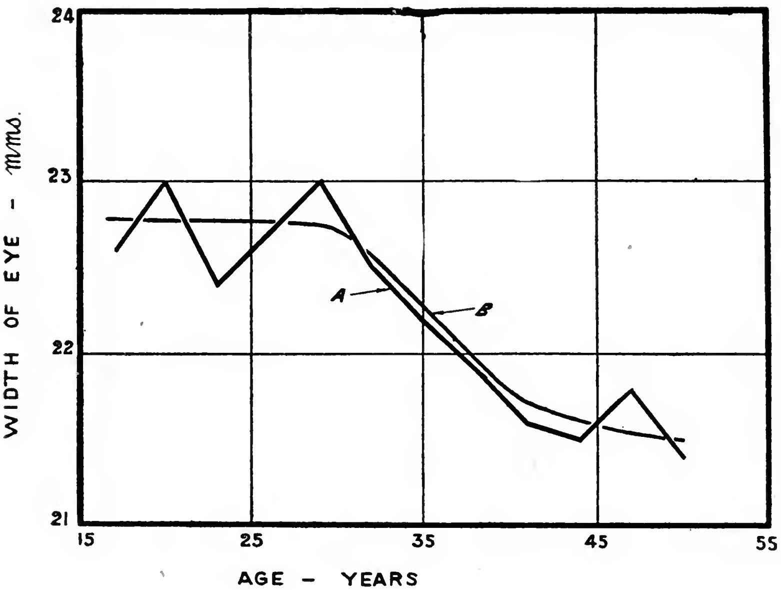

Fig. 4.

between the interocular distance and the height of normally developed individuals, as is indicated by Fig. 4. The more rapid rise at the right end of the curve is probably due to the small number of very tall people among those tested.

A curve less easily understood is that represented in Fig. 5 (curve *A*). It shows the variation with age of the width of the exposed portion of the eye. Abscissae represent ages and ordinate widths of eye. At thirty years of age the average curve *B* rapidly falls and at forty-five years tends to become level again. The decrease in width appears

to be due to the sinking of the eyeball within its orbital cavity, arising possibly from a shrinkage of the adipose tissue lining the cavity. That the eyes should sink in old age is to be expected. It is somewhat surprising to find

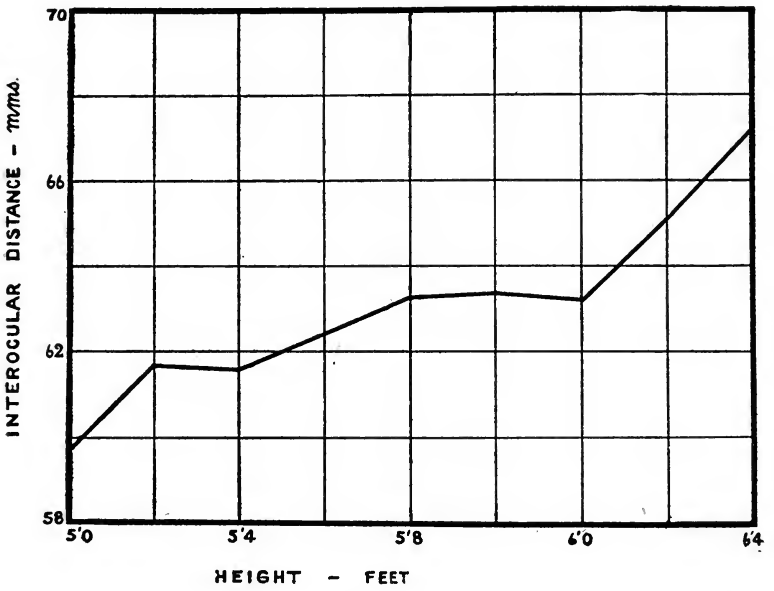

Fig. 5.

so early a commencement of this appearance as the curve would seem to indicate.

No very wide variation of the iris apparent diameter was observed. The smallest diameter was 10 mm. and the largest 13 mm., and the average for all individuals tested was 12 mm.

(Abstracted from the *Transactions of the Optical Society*, Vol. XXIII, page 44, 1922.)

Problems in Prescribing Prisms

R. H. Satterlee, M.D.

THERE is quality as well as quantity of fusion. It has always been taken for granted, the greater the heterophoria, the stronger the stimulus necessary to produce fusion and thus bring about binocular single vision. Hence a low muscular error was not supposed to require much stimulation to bring about fusion, and could be safely ignored. This has not always resulted in complete comfort to the patient in an otherwise careful correction of the refraction. In a case of low muscular error, due to causes unknown, the stimuli sent to the muscles are not proportionally distributed and a heterophoria, temporary or permanent, uses all available nerve force to establish and maintain single vision. We occasionally find a lax condition of all the eye muscles, with a slight weakness of one group or single muscle. In a case of this sort, the quality not the quantity of stimulation to govern the fusional faculty requires as much relief as those showing much greater muscular error. This leads to the question of the possibility of testing the power of fusion. To a limited extent the duction tests do this, but these do not tell whether there is a strain in the fusion faculty or not. The prisms used in the duction tests cause the retinal images to separate and fusion unites them, so the tests measure the utmost distance between retinal images that fusion can overcome. This is a measure of the quantity of fusion, but does not give us any idea of the quality.

The rotation will vary, the seeming amount of heterophoria will vary (sometimes from a systemic disturbance), lack of attention to what we are to bring out, and sometimes to a weariness from too prolonged a test.

One reason for our uncertainty is because we are prone to consider the eye muscle as an entity instead of part of the human economy. An abnormal stimulation sent to one

muscle will mask a condition that defies detection; and to uncover this, is often very difficult.

Marlow for years has advised making the patient wear a patch over one eye for weeks, to relax the muscle and bring out the true status.

In the determination of the accommodation-convergence relation we are all at sea, for we have to depend on the intelligence of the patient.

To sum it up, the whole thing is in a crude and elementary state. Dissociation to start with is unnatural and develops or masks conditions that do not ordinarily exist. The tests seem to vary in the findings to such an extent, one is often perplexed to determine what is really the true state and having found it to your satisfaction what to do. In a case of weakened interni, some get relief from bases in, some from bases out, some will not tolerate any prismatic correction.

According to Savage, with a horizontal prism placed before one eye, only one nerve is excited and only one eye muscle is brought into a state of contraction; but if the prism is turned to a vertical position two nerve centers are excited—one to depress or elevate the eye—and the other to prevent torsion.

Many cases of ill health will develop a temporary weakened convergence which becomes normal on recovery. For many years the writer took care of a physician's wife who periodically overworked and when run down she always required a ½ degree prism, base down, which relieved her at once but as soon as she became rested the prism was intolerable.

Bannister, in his paper, says about 40 per cent of healthy individuals who never had a symptom of eye trouble have some degree of heterophoria. We occasionally find a case that indicates in every way a correction for a deviation yet will not tolerate any prismatic addition whatever. We seem to have drifted along the lines of least resistance. Putting at rest a weakened eye muscle gives comfort so we

prescribe a prism for that purpose. This seemingly gives relief for a time, then becomes intolerable probably because nature revolts against putting a weak muscle at rest.

Taking a 4 degree base up, over the right and a 4 degree base down over the left, and using the familiar arrow test we find in what we consider a normal balance that it requires a 5 degree prism, base in, to merge the arrows. If normally we as a race are divergent—as the tests seem to prove—we are all handicapped from the start if we do any prolonged near work. In writing prescriptions this condition is usually provided for by incorporating a prism base in for near work or shortening up the focus by adding plus lenses. If the latter proves the more comfortable then our other tests are wrong and we have drawn the wrong conclusions as to the amount of refractive error.

Discussion

In the discussion which followed Dr. L. M. Francis said that he was inclined to prescribe for vertical imbalances and that a right hyperphoria is productive of more symptoms than a left hyperphoria. A good many cases of lowered convergence ability and lowered lateral imbalance often show a latent or obvious amount of hyperphoria, the correction of which causes a disappearance of the difficulties from which the patient is suffering.

Various other opinions expressed by Drs. Hubbard, Blaauw, Clemesha, Bennett, Phillips, Edison, F. Park Lewis, Finnerty, and Cowper contain the following points:

1 Never prescribe a prism on one examination, but only after three or four examinations.

2 There is considerable influence on the part of subnormal accommodation, which must be considered.

3 The muscles should be tested at near as well as far. Test for imbalances at a foot and then at twenty feet away and make both sets of tests before prescribing a prism.

4 Rarely prescribe a prism with the base in or out. [The

editor would agree with this except to make these comments: (1) When a lateral prism is really needed it should not be withheld and (2) a prism, base out, should be a rarity.]

5 In exophoria a great deal is accomplished by muscle training.

6 The prescribing of prisms for vertical imbalance is worthy of attention and consideration.

(Abstracted from the *American Journal* of *Ophthalmology*, Vol. 4, p. 626-8, 1921.)

The Vision of Railway Men

Leonard J. C. Mitchell, M.B., B.S.

IN order to arrive at some more definite relation between vision as tested by test-types under good conditions, and what may be termed "safe vision" from a railway point of view, a series of tests was undertaken recently (1920) at Tottenham (Vic.). Previously (1898) Barratt, Orr and Murray had conducted similar tests, but their data were too meagre to give any definite result, and further, the main object before these experimenters was to prove that what is called a "practical test" is, by itself, very misleading. Later (1914) Gault, Webster and Ryan, in collaboration with Stanley and the writer, conducted a test with a special signal, but it would seem that fallacy was introduced by first reducing with glasses the vision of persons examined. The New South Wales Railway Medical Officers have recorded a test in which the persons examined had vision below normal, but the fallacy of their test was that there was a different background for the various signals used. Bearing in mind these unsatisfactory results, the Tottenham experiment was planned and carried out by H. R. Stanley and the writer, on the afternoon of a cloudy calm day, a special

standard signal was erected, and the sky was the background throughout the tests.

A standard signal arm (Vic. Rlys.) measures 4 ft. 9 in. by 10 in., and this arm subtends an angle of five minutes at a distance of 1,085 yards. It might be inferred from Snellen's figures that such a signal arm would be read accurately by a person with 6/6 vision at that distance and no further, but the signal can be read by a normal-sighted person up to a distance of 1.5 miles. Testing vision by test-types implies a good illumination, and if we are to form an opinion as to the relation between form vision as tested in the consulting room, and the ability to read signals accurately, it is necessary to test that ability under good conditions of illumination and backgrounds. Further, it must be remembered that normal vision is, as a rule, very much better than 6/6, probably 6/4 would be nearer the mark among a large number of normal sighted, and so the results of the described below are not as surprising as would first appear.

The subjects for examination were locomotive drivers, signalmen and station masters, and each man's vision was tested with test types under the best indoor conditions immediately before the outdoor test was begun. One man, with vision R. 6/12, L. 6/12, combined 6/9, read the signal accurately at 1,760 yards, two others with the same vision were accurate at 1,600 yards, and another at 1,500 yards, men with vision, R. 6/18, L. 6/18, combined 6/12, were accurate at from 1,500 to 1,600 yards.

The variations in the ability to read signals amongst men whose vision was the same as when tested indoors, was undoubtedly due to the nature of the error in the individual cases, that is, whether the error was astigmatism or simple hypermetropia. (A temporary light smoke haze obscured the view at one stage, but it was shown that a different visibility of as much as 300 yards was made.)

It is, therefore, clear that we have here a definite relation

between the vision of a man whose best vision is 6/12 with both eyes open as tested indoors, and the distance at which he can read signals under good conditions. In other words, a relation between certain degrees of defective vision, and the practical value of such vision from a railway point of view, has been established.

As a matter of railway practice, the signals are so arranged as to come into view at 600 yards distance as a minimum. (This does not apply to automatic signals.) So it would appear that there is an ample margin of safety as regards the distance at which a man with 6/18, 6/18, 6/12 vision can see signals.

With regard to the seeing of the signals at night, the lamp glass of a standard signal (Vic. Rlys.) is 5 in. in diameter, but the candle power of the lamps depends much on the cleanliness of the glass, etc. As a point of light is very much more readily seen than the form of a letter, the size of the lamp glass does not bear the same relation to the distance at which the lamp is visible, as in the case of form vision.

The same men were tested with the Edridge-Green lantern immediately after the outdoor test, and it was shown that each man with vision 6/18, 6/18, both 6/12, was quite accurate with dull red lights. This is our everyday experience, and we hold that if the form vision is not reduced below 6/12 with both eyes open, the colour perception is safe—always excepting toxic amblyopia. A short red end to the spectrum should not be diagnosed unless the vision is improved to 6/6, or unless a large (half-inch) aperture be used.

Conclusions

1 Under ideal conditions a man with vision R. 6/18, L. 6/18, both 6/12, can, with both eyes open, read signals accurately at 1500 yards.

2 Provided that the vision with both eyes open is not below 6/12, colour perception is not *dangerously* lowered.

(Taken from *The British Journal* of *Ophthalmology*, Vol. VI, p. 319-21, 1922.)

Persistent Accommodative Spasm Due to Latent Hyperphoria

F. W. Marlow, M. D.

WHY some people accept readily a full correction of their hypermetropia and astigmatism as determined under cycloplegia, and some do not, is a problem the solution of which is often unsolved.

De Schweinitz states the problem thus: "After the effects of the drug have disappeared distant vision is often dim with the full correction, and a haze seems to lie over all distant objects, which disappears when the glasses are removed.

"Spasm of accommodation is the disturbing factor in this problem, and it is so variable in different individuals, that no precise rule can be given. Many persons wear a full correction with comfort, and do not need any modification, others will tolerate only a small part of the full correcting glass."

My own experience would lead me to modify slightly the last sentence and to say that a large percentage accept a full correction (—0.25D.), and a small percentage only do not. What are the factors in this small percentage which tend to maintain this accommodative spasm? The key to the solution of some problems of this kind is to be found in another paragraph of de Schweinitz—which says:

"A frequent cause of inability to wear a full correction depends upon the development of convergence insufficiency, causing an associated action of accommodation with the

muscular action necessary to bring the visual axes in a parallel condition."

While it is not obvious how a convergence insufficiency would be operative in distant vision, it is easy to see how a divergence excess would have precisely the effect described in the latter half of the paragraph, and that any one of a number of muscle anomalies may operate in just this way. In other words any excessive muscular effort necessary to bring the visual axes into parallelism may induce associated accommodative effort in excess of that necessary to maintain clear vision.

Correction of Heterophoria

I have observed in more than one case in which at the post-cycloplegic examination the patient would not accept the full correction, that the placing of prisms in the trial frame to correct, wholly or in part, a manifest heterophoria will at once raise the vision or permit the acceptance of a stronger lens.

But in many cases there is no demonstrable heterophoria, or the correction of what heterophoria can be demonstrated does not bring about the desired result.

The following case, in which a high degree of hyperphoria was revealed by the prolonged occlusion test, and its correction followed by relief from symptoms suggests a possible solution of many other unexplained cases.

Case

H. G. W., a medical student, seen first on Nov. 10, 1908, when he was 24 years old. He was complaining of his eyes getting inflamed, some aching, and other very slight asthenopic symptoms.

Examination showed: V.=R. 6/6 —, +0.37 S⊃+0.37 C 110° 6/6+; L. 6/6, —0.25 S⊃+0.62 C 85° 6/5—orthophoria.

After scopolamin: R 6/60, +1.00 S⊃+0.75 C 95° 6/5 —; L. 6/60, +1.00 S⊃+0.87 C 85° 6/5.

At a post-cycloplegic test: R. accepted—0.25 S⊃+0.62 C. 95°; L. accepted —0.25 S⊃+0.62 C 85°.

He was ordered: R. +0.50 Sph. ⊃+0.50 C 95°; L. +0.50 Sph. ⊃+0.62 C 85°.

He received no benefit from the glasses, which also blurred distant objects, and after a month or a longer time gave them up.

In 1911 he was re-examined: R. accepted —0.25 S ⊃+0.50 C 85°; L. accepted —0.25 S⊃+0.87 C 95°, right hyperphoria ½°.

After scopolamin: R. 6/60 +1.00 S⊃+0.87 C 95°; L. 6/60 +0.75 S⊃+1.12 C 90°; right hyperphoria 1°.

At a post-cycloplegic examination seven days later: R. accepted —0.25 S⊃+0.75 C 95°; L. accepted —0.25 S⊃+0.87 C 85°; right hyperphoria 1°.

He was ordered: R. +0.50 S⊃+0.75 C 95°, ¾° prism base down, L. +0.25 S⊃+0.87 C 85°, with the same result as before. After a persistent trial of some months he gave them up and went without glasses until April, 1920, when he came again on account of recent inflammation of eyelids and general exhaustion after prolonged reading.

R. now accepted +0.25 Sph. ⊃+0.37 C 95°; L. now accepted —0.25 S. ⊃+0.62 C 75°; R. hyperphoria 1°, esophoria 2°.

After scopolamin; R. accepted +1.25 S⊃+0.75 C 90°; L. accepted +1.00 S⊃+1.00 C 80°; R. hyperphoria ½°.

He was ordered: R. +1.00 S⊃+0.62 C 90° ⊃½° prism base down; L. +0.75 S⊃+0.87 C 80°.

On June 1st he returned complaining of blur and discomfort, vision being 6/18 with the glasses, brought up to 6/6 with the addition of —0.50 Sph. His spherical correction was reduced 0.25 Sph. in the hope that his accommodation would relax enough to accept the remaining correction, but a year later, June 2, 1921, having worn the glasses constantly in the interval, he still complained of blur for distance, disinclination to read, and fatigue afterwards.

R. accepted +0.25 Sph. ⊃+0.37 C 75°; L. accepted +0.62 C 80°, or about the same as at his first examination on November 10, 1908. In other words the accommodative spasm remained unchanged.

Test of the muscle balance now showed R. hyperphoria 1¾°, esophoria 2°; p.p.c. 5 cm. from base line; abd. 3°–5°, exophoria at $^1/_3$m. with his glasses 3°–4° prism; p.p. with his glasses, normal.

It had become evident that the simple correction of his refraction, full or partial, continued over a long period of

time, was having no effect upon the accommodative spasm, that the latter could not be attributed to insufficiency of convergence, for that was above the normal standard, that moreover the correction of what manifest hyperphoria could be detected had no influence in relieving the symptoms, and the question seemed to arise naturally as to whether there might not be a higher degree of heterophoria present than could be demonstrated which might on account of its necessitating increased innervation of extrinsic muscles induce also an excessive accommodative effort. In order to test this one eye was occluded with a ground glass and the effect watched. The test lasted seven days. The right hyperphoria increased until on the seventh day it reached 5-½°. The esophoria diminished until on the seventh day it disappeared entirely.

He was ordered: R. +0.75 Sph. ⊂ +0.62 C 85°, 2° prism base down; L. +0.50 Sph. ⊂ +0.75 C 80°, 1½° prism base up. This correction gave prompt relief from symptoms and clear distant vision, and he has remained comfortable since.

(Taken from the *Archives* of *Ophthalmology*, Vol. LI, p. 223-226, 1922.)

Hereditary Influence Affecting the Color of the Eyes

Drs. Davenport and Hurst

(From the Berlin correspondent of *The Journal of the American Medical Association*)

DAVENPORT and Hurst, on the basis of their statistical investigations, have expressed the view that the hereditary transmission of blue and brown eyes takes place in accordance with simple Mendelian laws pertaining to the transmission of types—that brown is dominant over blue. In reality, however, things seem to be somewhat more complicated, in proof of which Winge recently furnished some interesting statistics. Winge ascertained the hereditary facts affecting about 1,400 children. Of 637 offspring resulting

from marriages in which both parents had blue eyes, 625 children had blue eyes, and 12, brown eyes. Of 639 offspring resulting from marriages in which one parent had blue and the other parent brown eyes, 317 children had blue eyes, and 322, brown eyes. Of 441 offspring resulting from marriages in which both parents had brown eyes, 25 children had blue eyes, and 416, brown eyes. Doubtful cases (grayish green, bluish green) are omitted from these findings. It will be seen from these statistics that there were brown-eyed children among the descendants of blue-eyed parents, although only a small percentage (2 per cent). This would scarcely be the case if brown actually dominated over blue. One is inclined to assume that in certain cases one of the parents was only disguisedly and not inherently blue-eyed; that, at the same time, an inhibitive factor was at work which did not allow brown eyes to develop. This factor seems to affect also the other qualities of the eye. Thus, Winge often observed in the critical cases astigmatism, weak vision and similar defects.

The findings in the combinations of brown and blue, and brown and brown appear to accord well with the Davenport hypothesis. In the first case—brown and blue—almost the same number of brown-eyed and blue-eyed children resulted. Since in Denmark the brown-eyed persons are almost all heterozygotes, the data that were found were to be expected according to Mendelian laws. In spite of this fact, the matter is not so simple. If we consider among the offspring the matter of sex, it will be seen that among the females there is quite a considerable excess of brown eyes. This is a fact that the earlier statistics of various countries also brought out. As Winge shows by a detailed analysis of his statistics, all the various data can be harmonized with the preconditions as stated, especially the fact that the reciprocal marriages between blue-eyed and brown-eyed parents (father blue-eyed) and brown-eyed and blue-eyed parents (father brown-eyed) gave entirely different results. The

effect of sex on transmission has been shown in man with regard to various characteristics, such as color blindness and blood diseases.

(Taken from the *Journal American Medical Association*, Vol. 79, p. 1784, 1922.)

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The American Journal *of* Physiological Optics

A Critical Study of the Snellen Letters and the Illiterate "E" Tests*

For the Acuteness of Vision of School Children, and a Proposed Substitute for These Tests

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OCULISTS, opticians, nurses and teachers test the acuteness of vision of millions of children and grown up people every year. Most of these tests are made with the "Snellen Alphabet Test" for literates, or with the "Snellen E," directed up, down, right or left for illiterates.

These tests have been used so long and so universally that no one, scarcely, has thought to question their validity or search for other and better means of measuring the acuteness of vision.

Because of the variation in results obtained by myself in using the Snellen letters and "illiterate" E, I was led to make tests in a very careful scientific fashion as follows:

The acuteness of vision of 470 school children in different grades was most carefully tested, under exactly the same conditions as to light, distance, and the time the letters were exposed. Snellen letters and the Snellen "illiterate" E, each constructed to be seen by the normal eye at 16 ft., were used in these tests.

*The substance of this article was read before the Optical Society of America which met at Washington, D. C., October, 1922.

TABLE I

The distance in feet at which the eyes of 470 pupils of the Centennial Grammar School, Trenton, N. J., distinguished the Snellen Alphabet and Illiterate E.

Feet.	Grade VIII		Grade VII.		Grade VI.		Grade V.		Grade IV.		Grade III.		Totals. III.-VIII.		Gr. II.	Gr. I.	Totals I and II	Totals AllGrds.
	Alph.	Illit.	Alph.	Illit.	Alph.	Illit.	Alph.	Illit.	Alph.	Illit.	Alph.	Illit.	Alph.	Illit.	Illit.	Illit.	Illit.	Illit.
0																		
1	1	0	0	0	1	0	0	0	0	0	4	1	6	1	0	4	4	5
2	1	0	0	0	0	0	1	0	0	0	1	4	3	4	0	2	2	6
3	6	1	4	0	0	1	1	0	0	0	3	0	14	2	0	0	0	2
4	2	1	0	1	3	0	1	0	0	0	0	0	6	2	2	3	5	7
5	0	0	4	0	0	0	1	1	0	0	2	2	7	3	0	0	0	3
6	4	5	7	3	2	1	5	0	1	0	7	1	26	10	3	1	4	14
8	5	6	20	4	1	0	0	1	9	1	7	1	42	13	3	6	9	22
10	5	1	39	2	2	3	7	1	11	1	23	4	87	12	4	4	8	20
12	26	2	46	10	6	1	12	4	7	0	17	1	114	18	3	3	6	24
14	43	2	54	21	12	0	22	0	10	2	7	5	148	30	6	3	9	39
16	34	3	45	13	15	2	23	3	10	2	1	4	128	27	11	7	18	45
18	14	17	23	24	8	1	6	4	6	9	6	5	63	60	5	16	21	81
20	3	25	12	40	3	4	3	1	2	7	0	9	23	86	7	8	15	101
22	4	25	4	41	5	1	0	8	0	9	0	10	13	94	10	11	21	115
24	6	28	2	38	0	4	0	4	0	5	0	13	8	92	18	38	56	148
26	0	18	0	21	0	8	0	5	0	1	0	5	0	58	24	18	42	100
28	0	6	0	24	0	2	0	18	0	7	0	6	0	63	6	15	21	84
30	0	1	8	0	0	7	0	20	0	5	0	6	0	47	4	5	9	56
32	0	4	0	6	0	9	0	6	0	3	0	1	0	29	2	0	2	31
34	0	3	0	4	0	4	0	5	0	4	0	0	0	20	0	0	0	20
36	0	6	0	0	0	2	0	1	0	0	0	0	0	9	0	0	0	9
38	0	0	0	0	0	4	0	0	0	0	0	0	0	4	0	0	0	4
40	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	2
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	2
Total No. of Eyes	154	154	260	260	58	58	82	82	56	56	78	78	688	688	108	144	252	940

CURVE I. CURVE II. CURVE III. CURVE IV.

All grades, III to VIII inclusive, were tested with both the alphabet and the "illiterate" E. Grades I and II were tested with the "illiterate" E only. Table I shows the distribution of pupils or eyes according to acuteness of vision, by grades. The same distribution is shown graphically in Figure 1.

Results of Tests

In Figure 1, the numbers at the left represent pupils and the numbers beneath the graph represent feet. The straight line a-b, erected at the 16 ft. point, represents the line of assumed normal vision, when the 16 ft. letters or the 16 ft. "illiterate" E's are used. According to this assumption, all pupils who cannot see the letters or the "illiterate" E have subnormal vision, all pupils who can just see them at 16 ft. have normal vision and all pupils who can see them at a greater distance than 16 ft. have vision above normal.

Curve I shows the distribution of the acuteness of vision of 688 eyes as shown by the Snellen alphabet test. Curve II shows the distribution of the acuteness of vision of these same 688 eyes, tested by the Snellen "illiterate" E test. It should be borne in mind that the normal eye is supposed to see both the alphabet and the "illiterate" E's at 16 ft.

Curve III shows the distribution of the acuteness of vision of the 252 eyes of pupils in the first and second grades as determined by the "illiterate" E test alone. Curve IV is a combination of Curve II and Curve III.

From these curves and from Table I, we deduce the following:

Grade	*Test*	*Eyes Normal*	*Eyes Subnormal*	*Eyes Above Normal*
III to VIII	Alphabet	128 or 18.6%	453 or 65.8%	107 or 15.5%
	Illiterate E	27 or 3.9%	56 or 8.1%	566 or 82.2%
I and II	Illiterate E	18 or 7.1%	47 or 18.7%	187 or 74.2%

It is evident at a glance, that something is wrong, either with the letters used or with the "illiterate" E, since the results were obtained under exactly the same conditions. It is not possible for both results to be correct, because, with the "illiterate" E, 8.1 per cent of the pupils tested were subnormal and 82.2 per cent were above normal;

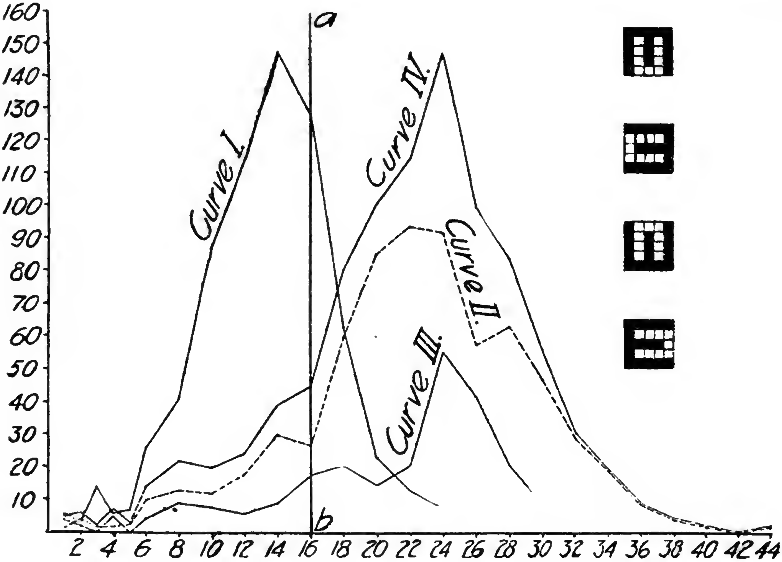

Fig. 1. Curves showing distribution of acuteness of vision with different test objects.

whereas, with the alphabet test, 65.8 per cent of the same pupils were found to be subnormal and only 15.5 per cent above normal. The fact that only 3.9 per cent of the pupils, according to the illiterate test, had normal vision, and only 8.1 per cent were subnormal, would warrant the suspicion that something is wrong with the "illiterate" E, as a reliable measure for acuteness of vision. A close analysis of this character will prove that the suspicion is well founded. The structure of the "E" is shown at the right of Graph I.

A pupil being tested with this character has only to determine in which one of the four directions—up, down, right or left—the opening of the character is directed, and this opening can always be pointed out by observing that this side of the E is always the brightest. Each of these characters is constructed in a square which is subdivided into twenty-five squares. The normal eye is supposed to be able to discern one of these small squares at the same distance at which the E, turned in different directions, can be recognized. It will be observed that there are three of these small squares lying together unfilled on the open side of this character. Four of these small squares, arranged in the form of a square, have twice the diameter of the small square and should be discerned at twice the distance, or 32 feet. It would, therefore, be reasonable to suppose that these three unfilled squares lying one above the other should be seen at about three-quarters of that distance, or twenty-four feet. As a matter of fact, this is exactly the distance at which they were discerned by the largest number of pupils of all grades.

Tests with Literate and Illiterate Test-Objects

This comparative test proves conclusively that sixteen feet is not the distance at which the normal eye can just discern the "illiterate" E. In fact, twenty-nine eyes were found, exhibiting normal vision with the alphabet test, that could interpret these characters at twice sixteen feet.

It is evident, then, that if this character is to be used for testing the acuteness of vision, a new distance, at which the normal eye can just see it, must be determined or the size of the characters must be changed. Either or both of these changes can easily be deduced from the results obtained by these tests.

Assuming that sixteen feet is the distance at which the sixteen-foot letter can just be made out, by the average normal eye, then, the same relative variation from this normal sixteen foot distance, would be found to obtain in

any sized letter or characters used in a series of tests. For example, if a series of tests with the sixteen foot letter should show that the eyes tested could see the letters at an average distance of only twelve feet, or one-fourth less than the normal distance, and, if another series of tests, made on the same eyes with another set of letters of any given uniform size and structure, should show that they could be seen at twenty-four feet, then the distance, twenty-four feet, should vary as much from the normal distance at which such letters should be seen, as twelve feet varies from sixteen feet, which is the normal distance at which the sixteen foot letters should be seen. It is evident that the distance twelve feet is one-fourth less than the normal distance sixteen feet, and, since the same relation must exist in the series of tests which showed that the average distance at which letters or characters could be seen was twenty-four feet, then this distance, twenty-four feet, is one-fourth less than, or three-fourths of the distance at which the normal eye can see these letters or characters. If twenty-four feet is three-fourths of this normal distance, then the distance at which the normal eye should see these letters or characters is 4/3 of 24 feet, or 32 feet.

In the series of tests described above it was found that the average distance at which the 688 eyes could just see the sixteen foot letters was 13.7 ft., and the average distance at which the same 688 eyes could see the "illiterate" E at the same time was 23.2 ft. The distance at which the normal eye can see the sixteen foot letters is 16/13.7 of the average distance at which the letters were seen. Since the same relations must exist between the normal distance at which the "illiterate" E can be seen and the average distance at which it was seen, we find this normal distance by taking 16/13.7 of 23.2 ft., the distance at which the "illiterate" E could be seen. This gives 26.4 ft., which is the distance at which the normal eye can see the "illiterate" E used in these tests, instead of sixteen feet as was given by Snellen.

Having discovered the great discrepancy between the results obtained by using the alphabet test and the "illiterate" E test, I undertook further experiments to make a possible improvement in the method of using the Snellen alphabet test, and to find a satisfactory substitute for the "illiterate" E test.

The Snellen alphabet test for acuteness of vision has the following faults:

1 It is often difficult to place the card in a satisfactory light.
2 It cannot be used to test illiterates.
3 The one using the test should have an assistant to point to the letters the subject is to read.
4 When several persons, or, in the case of school children, hundreds are to be tested, only one can be allowed in the room where the testing is being carried on. The others would memorize the letters if allowed to be present while tests were being made.
5 The card is an inconvenient thing to store or to carry from place to place, and, when kept hanging on the wall, it becomes discolored and, consequently, is rendered useless for reliable testing.

New Experimental Test Cards

I have devised a new set of alphabet vision tests which effectively does away with all of the above faults of the Snellen test card and in addition this new set has other advantages not possessed by the Snellen test card.

This new set consists of twelve square cards about 5x5 inches, on which are printed forty-eight letters of four sizes, one letter of each size on each card, no two cards having the same letters on them. The different sized letters can be seen by the normal eye at 20 ft., 30 ft., 40 ft., and 50 ft., respectively. These four letters, on each card, are placed so that one appears one-half inch from each margin and equally distant from the sides. They are printed in such a way that only the letter at the top of the card is in a position to be read when the card is held in an upright position.

The tests are made with these cards exactly as tests are made with the ordinary test cards, except that the operator

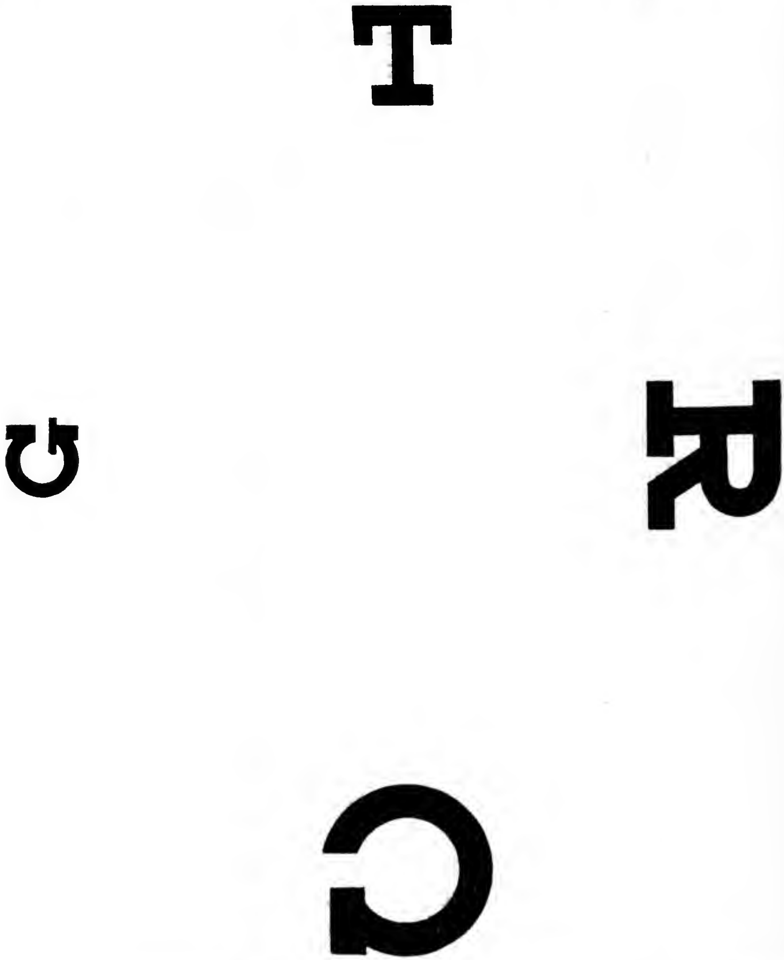

Fig. 2. Showing the four sizes of letters and their arrangement on one of the twelve cards used in these tests. The smallest of these letters can be seen by the normal eye at 20 feet; the next larger, 30 feet; the next larger, 40 feet; and the largest, 50 feet. These tests—the McCallie Vision Tests for Literates—are copyrighted.

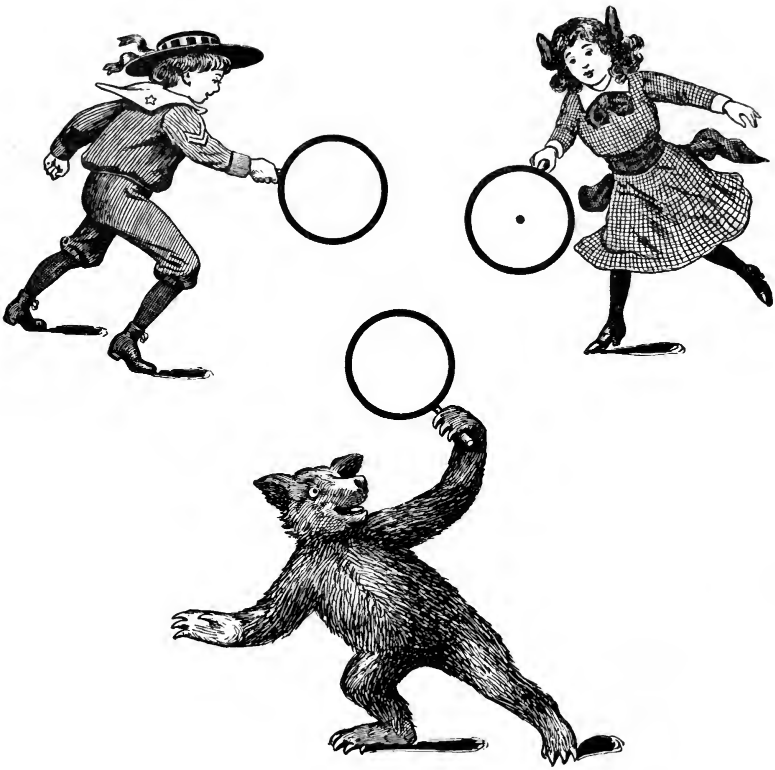

Fig. 3. Dot test for acuteness of vision showing one position of the dot.

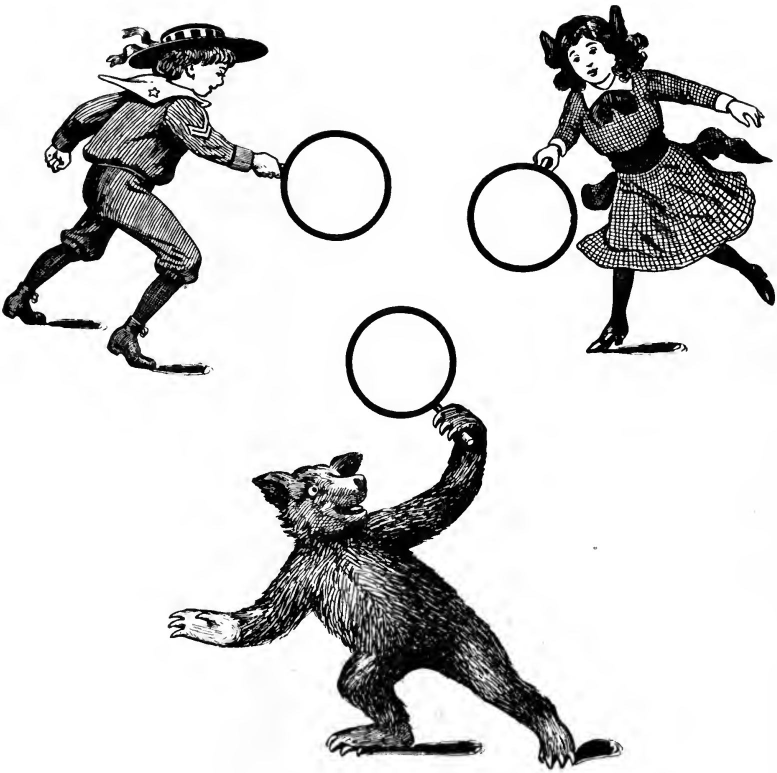

Fig. 4. Dot test for acuteness of vision showing absence of dot.

holds the cards in his hand and exhibits one letter at a time, by taking the cards one at a time from the back of the pack and placing them in front. Any one of the four sized letters may be used by simply giving the cards a quarter or a half turn in the hands. Any possibility of remembering the order of the letters may be prevented by now and then shuffling the cards. This makes it possible to test pupils in their own rooms and in the presence of all the pupils, if desired, and obtain trustworthy results. One of these cards is shown in Figure 2.

In searching for a substitute for the "illiterate" E test, I made use of the generally accepted fact that the normal eye can just discern an object that subtends a one minute angle, the vertex of the angle being the nodal point of the eye, where the rays of light cross before falling on the retina. According to this principle, an object that can just be seen by the normal eye, placed twenty feet away, must have a diameter of 0.0698 of an inch. I, therefore, used a black dot, having a diameter of 0.0698 of an inch in a series of tests of acuteness of vision.

To enable one to make tests with the dot rapidly and to add interest, a set of test cards was devised embodying the following somewhat novel features, as shown in Figure 3, Figure 4, Figure 5 and Figure 6.*

It takes ten of these cards to make a set. The dot in the ring is the object to be seen. There are three cards with the dot in the boy's ring; three with the dot in the girl's ring; three with the dot in the bear's ring; and one with no dot in either ring. All of the dots are identical in size.

The boy, the girl and the bear are supposed to be playing ball and each player is supposed to be trying to catch the ball in his racket. The dot is the ball and the rings are the rackets.

*These tests—the McCallie Vision Tests for Illiterates—are copyrighted and are handled by C. H. Stoelting and Company, 3037 Carroll Ave., Chicago.

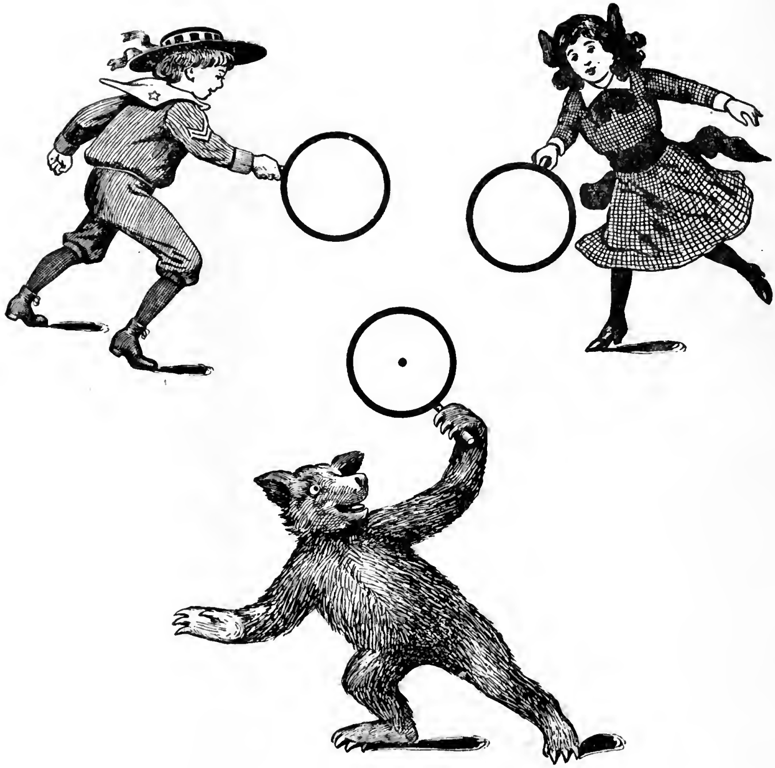

Fig. 5. Dot test for acuteness of vision showing a second position of the dot.

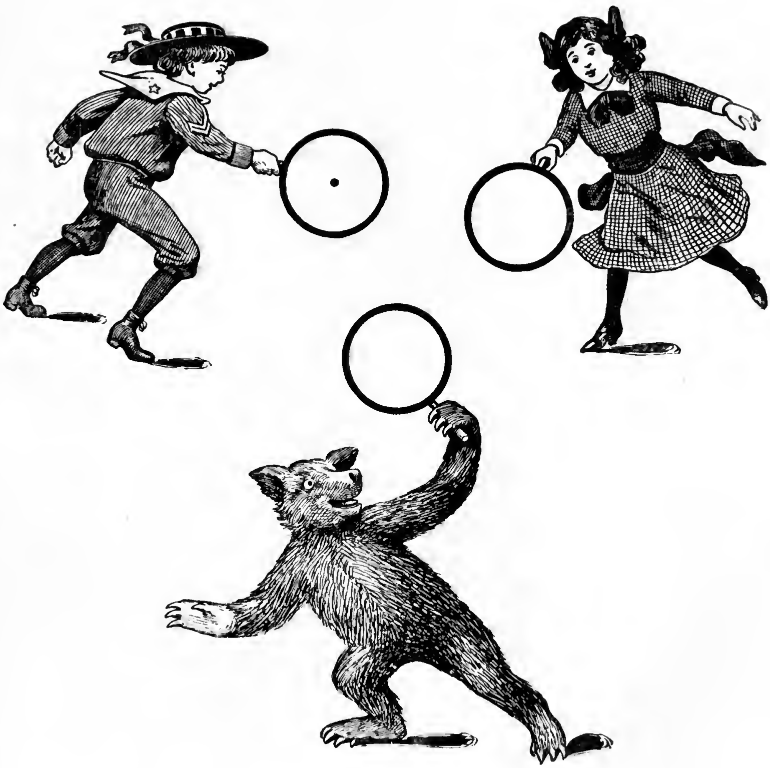

Fig. 6. Dot test for acuteness of vision showing a third position of the dot.

The tests were made in this way: The pupil to be tested was placed at a distance where the normal eye could just see the dot. The operator shuffled the cards and then held them up face toward the pupil. As the cards were taken from the back and placed in front, the pupil was required to tell which had the ball, by saying "boy," "bear," etc., or, if he did not see the dot at all, by saying "nobody has it." This method was found to have the great advantage of being easily understood by children and interesting to them. Even pupils in the kindergarten may be tested with these cards used as a game.

Two hundred pupils were tested with the Snellen 50 ft., 40 ft., 30 ft. and 20 ft. letters and with the 20 ft. dot test. The following shows the average distance at which each one of these tests could be seen.

The	50 ft.	letters	were	seen	54.47	ft.
"	40 "	"	"	"	43.13	"
"	30 "	"	"	"	33.50	"
"	20 "	"	"	"	22.20	"
"	20 "	dot was seen			20.90	"

These figures show that the dot test is a little more difficult to see than the letters when each is placed at the proper distance for the normal eye and that the average distance at which the 200 pupils saw the dot is more nearly the normal distance than the average distance at which the same pupils saw any of the different letters. This clearly indicates that the dot test is superior to the Snellen letters as a test for acuteness of vision.

None of the pupils tested seemed to have any optical defect that was detected by the letter test that was not detected by the dot test. The dot test is more nearly a test of pure vision than the letter tests. A pupil's familiarity with the general forms of letters will often enable him to guess correctly the name of the letter, although he may not be able to see all the parts of the letters. In the dot test

the pupil passes judgment solely upon whether the dot is present or absent, or whether there is or is not a retinal sensation produced by the dot.

Conclusions

The dot test is greatly superior to the illiterate E test because:

1 The dot is scientifically constructed and the "illiterate" E is not at present so constructed.

2 The dot test is interesting to children and the "illiterate" E test is not at all interesting. Without interest there can be no reliable test of vision.

3 The dot test is easily given by anyone and the directions to the one being tested can be easily understood and followed. It is difficult to give the "illiterate" E test to children and one cannot be sure that the complicated directions are being followed. While the dot test is especially valuable for testing foreigners and illiterates, literates may also be tested by this device with ease and the results obtained will be even more accurate than the results obtained by using the Snellen alphabet test.

Trenton,
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A Problem in Lens Effectivity

Ernest Petry

LET it be assumed that, by the most approved methods and with the most modern equipment, the following Rx has been determined:

O. D. + 4.00 D_V sphere
O. S. + 3.00 D_V at 90 $\supset$ + 4.00 D_V at 180
Meniscus form
Vertex distance 18 mm.

It will be noted that the lens powers are given in vertex diopters and that the left lens is prescribed in accordance with meridianal requirements, rather than by the old method of prescribing the combination of a sphere and cylinder, which latter is possible only in the event that flat compound lenses are used. The advisability of so noting compound lenses will be emphasized in the calculations concerning the effectiveness of the left lens for reading application.

Considering, first, the detail of the refractive correction, it will be necessary to refer to Figs. 1 and 2.

Let A represent the plane tangent to the back surface of the lenses and B, the plane tangent to the cornea while C and P. R. represent the retinal and punctum remotum planes respectively.

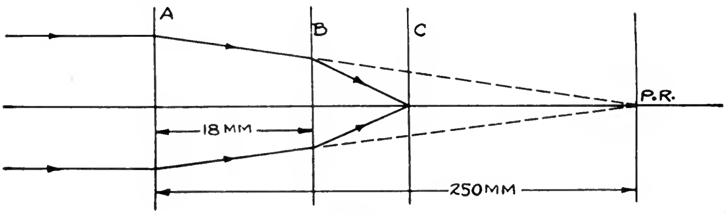

Fig. 1.

Fig. 1 represents the condition as it exists for O. D. and at the same time, that for the 180th meridian of O. S., while Fig. 2 is that for the 90th meridian of O. S.

An object at a remote distance being under consideration, the incident light for both lenses will be parallel and each refractive element in the lenses will cause rays to emerge from the back surface in a direction tending toward a focus in the respective far point plane. Therefore, the convergence produced as shown in Fig. 1 and measured in the planes A and B will be 1/250 and 1/232 or 4 D and 4.31 D respectively. In Fig. 2, this same consideration will present 1/333 and 1/315 or 3D and 3.17 D respectively. Thus, we may detect that if the error of an eye were noted by the amount of convergence or divergence which must be presented to the refractive system of the eye to enable its

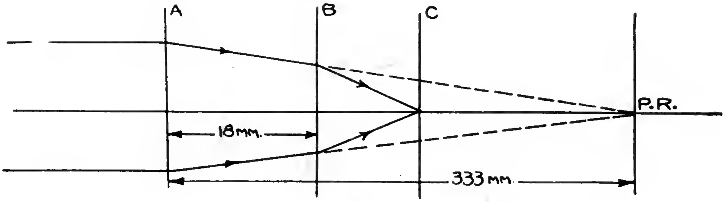

Fig. 2.

focusing rays on its retina, we have, according to our prescription, a right eye that lacked 4.31 D of refractive power and a left eye which lacked 3.17 D in the 90th and 4.31 D in the 180th meridian. Since ophthalmic astigmatism is quantitatively defined as the difference in refractive power of the principal meridians of an eye, the left eye under consideration has 1.14 D of astigmia while the difference in vertex dioptral power of the correcting lens is only one.

In this case, the foregoing may be of little consequence from a practical point of view, but it is enough to emphasize the advisability of noting the exact position of the back surface plane of our correcting lens before the eye. However, if we now attempt to apply these lenses for a reading distance of 333 mm. from the cornea, we enter upon a more complex problem.

To proceed accurately, it will be necessary for us to first determine the surface curvature of the lenses employed and the position of the principal planes in each case.

Assuming that the common meniscusity (6) is employed and directing our attention first to the right lens, we have the following formula: $D_V = \frac{N\,D_1}{N - D_1 t} + D_2$

For the known equivalents we have $N = 1.523$, $t = .0035$, $D_V = +4$ and $D_1 = +10$, and applying these gives us the following equation: $+4 = \frac{1.523 \times 10}{1.523 - .0035 \times 10} + D_2$. Solving for D_2, we obtain $D_2 = -6.24$.

Applying the same formula for the 90th meridian of the left lens, we have: $+3 = \frac{1.523 \times +6}{1.523 - .0035 \times +6} + D_2$. We obtain $D_2^{90} = -3.08$.

Now directing our attention to the 180th meridian and using the D_2 as obtained for the 90th meridian, we have $+4 = \frac{1.523 \times D_1}{1.523 - .0035\,D_1} - 3.08$ we obtain $D_1^{180} = +6.97$

Thus far, we have the following information:

	O. D. *All Meridians*	*O. S.* *90th Meridian*	*O. D.* *180th Meridian*
D_V	+4.00	+3.00	+4.00
Thickness	3.5 mm.	3.5 mm.	3.5 mm.
Index	1.523	1.523	1.523
Plane of correction*	18 mm.	18 mm.	18 mm.
D_1	+10.00	+6.00	+6.97
D_2	— 6.24	—3.08	—3.08
Ametropia	4.31 D. Hy.	3.17 D. Hy.	4.31 D. Hy.

*The distance from the cornea to the posterior pole of correcting lens.

Referring to this table, we may well argue the point:—"Is the ametropic condition properly stated, quantitatively, when the correcting lens power is noted?"

It takes but a moment's consideration to answer this question in the negative, for the reasons that, first, as the distance of the correcting lens from the cornea is varied, its power must be altered; and second, as the curvatures and thickness of the lens vary, the true dioptric power of the correcting lens will vary.

Thus, the ametropia may quantitatively be defined only by the amount of convergence or divergence which must be presented to the first corneal surface so that a focus may be produced upon the retina, when static refraction exists.

Having accepted this statement, we may further say that for hyperopic meridians, the ametropia is always in excess of the power of the correcting lens and less for myopic meridians.

The next question which presents itself, is: "How can we express the ametropia in terms of the correcting lens power?"

To do this in terms of true diopter is difficult because of the variable positions of the principal planes, but in terms of vertex diopter, it can be expressed by the following equation:—

$$\text{Ametropia} = \frac{D_V}{d.D_V - 1}$$

in which d equals distance from the cornea to the posterior pole of the lens and minus or plus answers indicate hyperopia or myopia respectively.

Although the foregoing has been expressed in perhaps a little different form from what has been given us by a number of authorities, nothing radically new is contained therein, but the writer would now direct your attention to the conditions that prevail when these lenses are applied for near work.

Since near work application brings finite conjugate foci

into our problem, and since our near application of a lens may concern either the central or an eccentric portion of our lens, we have too many aspects to consider in one article. Therefore, with the idea in mind to build up to a complete consideration and also so that "no stones will be left unturned," we will in this article limit ourselves to the central area of the lens. (The writer hopes to later present an article on the eccentric application.)

To apply finite conjugate foci, it is necessary to know the true dioptral powers and the positions of the principal planes of the prescription under consideration.

With the data already in hand, we can proceed by using the following formula:

$$D = D_1 + D_2 - \frac{D_1 D_2 t}{N}$$

$$H_1 = -\frac{t D_2}{N D} \text{ and } H_2 = \frac{t D_1}{N D}$$

Thus our true diopters will be calculated as follows:—

For O. D. $D = 10 - 6.24 - \dfrac{10 \times -6.24 \times .0035}{1.523} = +3.90$

" O. S. 90th $D = 6 - 3.08 - \dfrac{6 \times -3.08 \times .0035}{1.523} = +2.96$

" O. S. 180th $D = 6.97 - 3.08 - \dfrac{6.97 \times -3.08 \times .0035}{1.523} = +3.94$

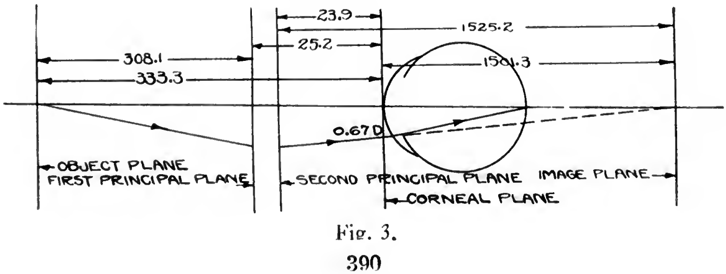

Fig. 3.

Then directing our attention to the principal planes, we determine the following:—

$$\text{For O. D.}\quad H_1 = -\frac{.0035 \times -.624}{1.523 \times 3.90} = .0037 \text{ or } 3.7 \text{ mm.}$$

$$H_2 = +\frac{.0035 \times 10}{1.523 \times 3.90} = .0059 \text{ or } 5.9 \text{ mm.}$$

$$\text{O. S. 90th}\quad H_1 = -\frac{.0035 \times -3.08}{1.523 \times 2.96} = .0024 \text{ or } 2.4 \text{ mm.}$$

$$H_2 = +\frac{.0035 \times 6}{1.523 \times 2.96} = .0047 \text{ or } 4.7 \text{ mm.}$$

$$\text{O. S. 180th}\quad H_1 = -\frac{.0035 \times -3.08}{1.523 \times 3.94} = .0018 \text{ or } 1.8 \text{ mm.}$$

$$H_2 = +\frac{.0035 \times 6.97}{1.523 \times 3.94} = .0040 \text{ or } 4.0 \text{ mm.}$$

Assuming a reading distance at 333.3 mm. from the cornea and referring to Fig. 3, we will determine the effectiveness of the lens before the right eye.

The equivalents as given in Fig. 3 were determined as follows:—The first principal plane is $H_1 + t + d = 3.7 + 3.5 + 18$ or 25.2 mm. in front of the cornea and subtracting this from 333.3 mm., we obtain 308.1 mm. as the object distance for the lens. Then applying this to the formula $V = \frac{u}{1 - Du}$ in which V equals the image distance, u = the object distance and D = the true diopter of the lens, we have

$$V = \frac{.3081}{1 - 3.90 \times .3082} = \frac{.3081}{-.202} = -1.5252 \text{ meters or } -1525.2 \text{ mm.}$$

From this we must subtract the distance from the second principal plane to the cornea, which is obtained by adding H_2 and d or $5.9 + 18 = 23.9$. Thus $1525.2 - 23.9 = 1501.3$. Converting this into its dioptral equivalent, we have, .67 D of convergence presented to the cornea and when we

consider that this eye must receive 4.31 D of convergence so that a focus can be created on the retina, the eye may be said to be obliged to overcome the difference between 4.31 D and .67 D, or 3.64 D of accommodation must be used. This last statement depends upon our conception of what the quantitative measure of accommodation is, but for the present, we will consider that our accommodative accomplishment is measured at the corneal plane.

Next let us take up the 90th meridian of the left eye and refer to Fig. 4, using the same object distance.

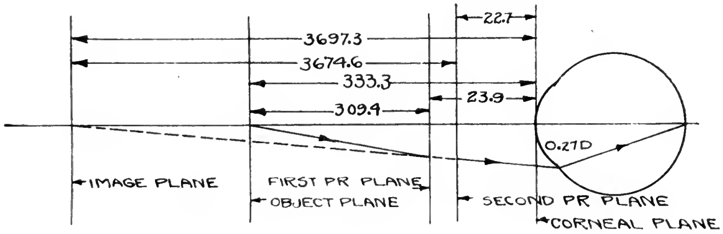

Fig. 4.

Having obtained our object distance for the lens in the same manner as for Fig. 3, we can again apply our formula $V = \frac{u}{1 - Du}$ and obtain $V = \frac{.3094}{1 - .3094 \times 2.96} = \frac{.3094}{.0842} =$ 3.9667. Adding to this the distance from the cornea to the second principal plane, we have $3674.6 + 22.7 = 3697.3$ and converting this into diopters, we note that .27 D of divergence is presented to the cornea, and since this meridian demands 3.17 D of convergence for a focus, we may say that the eye must accommodate 3.44 D for this meridian to focus the rays coming from the object.

For the 180th meridian of the left eye, we may in a similar manner obtain the values as given in Fig. 5.

From this we glean that with 0.67 D of convergence presented to the cornea the 180th meridian would be obliged to accommodate 3.58 D.

Thus, with the given prescription employed for an object distance of 333.3 mm., the following accommodative action is required:—

O. D. = 3.64 D, O. S. 90th = 3.44 and O. S. 180th = 3.58

In each case, we observe an increased requirement over that which our usual teachings have led us to believe, and also that the requirement varies as the contour and lens power vary, but this in no regular ratio. Also it may be stated that the problem in hand by no means exaggerates the condition for if we had taken the following problem using the same base curve and correction plane distance,

O. D. + 5.00 D_V
O. S. + 3.00 D_V at 90 ⊂ + 5 at 180

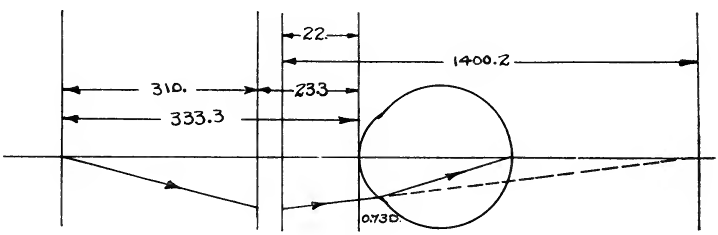

Fig. 5.

thickness 4 mm. and object 250 mm. from cornea, we would find that, instead of the 4 D of accommodation expected according to our present day methods, it would take 5.09 for O. D. and for the 90th and 180th meridians of O. S. 4.54 D and 5.01 D respectively, excesses of 1.09 D, .54 D and 1.01 D, which are not to be ignored.

From the fact as established by the foregoing that the remote and near effectivity of a lens are not equal, it is evident that dynamic skiametric findings obtained at a close working distance cannot agree with the distance correction; also when a dynamic near point test is conducted with the

distance correction, the point determined expressed in diopters is not equivalent to the amplitude of accommodation.

The practical application of the fact that there is a variance in the effectiveness of a lens as the object distance varies is particularly interesting for astigmatic corrections, and in these cases it may be proved that regardless of amplitude, it is impossible to correct a highly or moderately high astigmatic error with one lens for both distant and near application. A further conclusion and one which all refractionists should take cognizance of is that no compound lens can be correctly written as a sphero-cylinder but must be prescribed and written in accordance with their principal meridianal powers.

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Prescribing Prisms in Ocular Practice—II*

David Kletzky, D.O.S.

IV

TRUE ORTHOPHORIA VERSUS PSEUDO ORTHOPHORIA

IT is generally accepted, and rightly so, for a pair of naturally emmetropic eyes, or made so by lens correction[1], that when such are subjected under any of the tonicity or dissociation tests, at the six meter distance, the two visual axes must show a state of parallelism in the horizontal as well as in the vertical aspect; and such a showing is therefore recorded as orthophoria in the distance regard.

It is likewise rightly accepted that, when the aforesaid emmetropic eyes are tested under any of the tonicity tests at the near work or reading distance of about one-third meter, with accommodation naturally and normally alike active in each eye, the visual axes must show perfect parallelism in the vertical aspect, and at the same time should also show a retarded relative convergence, or a convergence insufficiency ("physiologic exophoria [?] in the near"), of not much over one meter angle, as measured in prism-dioptries, or, better still, by a suitable tangent scale, as devised by Dr. Maddox, in the horizontal aspect. Such a showing is likewise generally accepted and recorded as orthophoria in the near.

The reader will note that in the above paragraph we placed a question mark after the qualified term "exophoria." This we did because the *why* and *wherefore* of the stated amount of *exophoria* in the near test and its *physiologic element*, pretty generally accepted as a normal attribute under the

*This article is a continuation of the material which appeared in this *Journal* in the January, 1923 issue, pages 60-76.

[1]We hold that a showing of orthophoria, under the tonicity tests, in a pair of eyes having uncorrected ametropia of any kind is always a reflex or pseudo orthophoria.

near dissociation tests, has seemingly to the present time not been positively cleared up by any of the highly esteemed investigators of the oculo-motor reflexes[2]. The view we hold of the why and wherefore of the so-called "physiologic exophoria" and its stated amount, in the near dissociation tests, we shall, taking the risk of being considered pedantic, state thus:

We hold this convergence reflex, often termed "physiologic exophoria," which shows up under any of the near tonicity tests while the rest of the ocular muscle reflexes are normal or synergistic in action, to be a normal manifestation of the qualitative aspect of the innervational influence of the convergence function. But, before we shall give our reasons for the above statement, let us first consider if the term "exophoria in the near" expresses the condition of affairs under consideration.

If we recollect the position of the visual axes while they are under the influence of the near tonicity test we shall find, in a physiologic sense, that they are not exophoric, notwithstanding that the lower or the upper of the vertically doubled test object (doubled by a vertical prism before one eye), shows a lateral heteronymous displacement to the extent of, say, one meter angle as measured in prism-dioptries.

As proof of the above let us suppose that the lower or upper vertically doubled test object shows no lateral displacement at the one-third meter testing distance, then, each visual axis is, because of that, converged three meter angles for that distance. A lateral heteronymous displacement of either the lower or upper object to the extent of one meter angle between both eyes would still give to each visual

[2]Among these are Maddox, von Graefe, Howe, Worth, Eberhardt, Sheard and others. Maddox and, later, Sheard, after considerable experimentation, place this convergence reflex into a special subdivision of the convergence function and qualify the term "convergence" by the following adjectives:—*reflex*, *supplementary*, or, *fusion* convergence. (See *American Encyclopedia of Ophthalmology*, Vol. XV, pages 11858-11861.)

axis a convergence effect of two and one-half meter angles. This being the case, we think, the term "exophoria in the near" inapplicable to a condition in which the visual axes are held in a convergent state—supposed to have reached that state from their state of parallelism. Because the term "exophoria," as it is generally understood, means a tendency of either eye-ball with its visual axis to turn outward from the state of parallelism, and, also, because the visual axes under the near tonicity test are more or less *converged* from parallelism, therefore, the often used term "exophoria in the near" would, in a physiologic sense, convey a more accurate meaning if we supplement it by the more appropriate term "convergence insufficiency"—a term already well understood and made use of by many authorities. As the real intent is, by the use of the term "exophoria," to denote an outward turning tendency of the eyes and their visual axes from the state of parallelism, we can only make use of this term, in the one-third meter test, provided the degree of convergence insufficiency is greater than three meter angles for each eye or its visual axis. In such case, of course, the visual axes are really divergent from their parallel state, and the condition then becomes a real "exophoria in the near" if the case still comes under the heterophoric class—a possibility at times encountered in actual practice.

In passing, we shall state that we cannot differ much with the often used term "*esophoria in the near*," because a showing of esophoria in the near tonicity tests, evidenced by a lateral *homonymous* displacement of either the upper or lower of the vertically doubled test object, is a real tendency of the visual axes to over-converge for that particular distance from their state of parallelism. But, since we prefer to exchange the term "exophoria in the near" for the term "convergence insufficiency," for the reason already given, and, also, since the near lateral muscle tests are purely convergence reflex tests, therefore, we should likewise

prefer to designate the condition often termed "esophoria in the near" by a likewise often used term, "convergence-excess in the near." We have our preference for the suggested terms because we think that the distinct physiologic function of convergence and its anomalous aspect should be studied apart from the ocular coördination function for vision requiring parallel fixation of the visual axes; that is, directing our visual regard at objects at, or beyond, the six meter range. We shall, however, have more to say about the convergence reflexes later, because we do not desire, presently, to digress too far from the discussion of the main subject at issue.

We strongly hold the phenomenon, mostly and inappropriately termed, "physiologic exophoria," in the near tonicity tests, to primarily and normally become manifest because, in the first place, by the particular nature of the applied tonicity test we attack unawares, so to speak, the psychic fusion sense—the sense which so strongly dominates the function of ocular coördination for all distances of the visual regard. The fusion sense being so attacked, it sort of naturally rebounds and, therefore, in the second place, the internal recti muscles which, at the moment the test is applied, are holding the visual axes in a convergent state at the testing distance, momentarily repress or inhibit *part* of their contractile activities (because the fusion force no longer demands their inflexible functional coöperation), if they function under normal innervational influences. The amount of their contractile activities they thus repress under normal innervational influences of the convergence function has been found by many very careful observers (*loc. cit.*) of a large number of cases to not reach very much over one meter angle, as measured in prism-dioptries. Wherefore it was rightly fixed as "physiologic." But, a much greater amount is therefore also rightly looked upon, in a diagnostic sense, as a deficient innervational stimulus of the converging function; and, conversely, a quite lesser amount, or none at

all, or, at times, an over-convergence under the same test, is looked upon as an over-stimulus of the convergent function, *i.e.*, "esophoria in the near" or "convergence-excess" for that particular testing distance. We shall, moreover, have more to say about this anomalous condition "*convergence-excess*" when we take up the matter of the convergence reflexes in general.

Thus far we have given chiefly that which is the *general acceptance* of orthophoria as it shows up under the influence of the *ordinary way* of applying the different tonicity tests at the distance as well as at the near visual regard.

Since we have entitled the present subject-matter under consideration, "*true orthophoria versus pseudo orthophoria*"; and because we believe that we are, as far as our knowledge goes, for the first time, pointing out that there really is a possibility that an apparent orthophoria (as it shows up under the *ordinary and classical way* of applying the different tonicity tests) may be of such a *pseudo* nature that [*vide* premise (3), which the reader will find in the early pages which follow under the main title of the subject] quite often it may hide a grave spastic heterophoria of considerable degree; we shall, therefore, presently try, as far as we are able, to prove our contention not in theory alone but we shall also aim to establish this fact as it relates to our practical experience.

V

Because of our devotion to considerable and extensive experimentation with the innervational reflexes of the extra-ocular muscles we have learned to recognize some very marked characteristics in the behavior of the reflexes of certain groups of these muscles.

Moreover, we became convinced that while the act of coördinating both eyes at a point of fixation, in order to see singly, is a physical one, because all the extra-bulbar muscles must by the aid of the innervation affect a sort of gradual contraction in order to steady and thus rigidly hold

the visual axes at the point of regard (some, of course, contracting more, and some less, depending greatly upon whether the visual axes are to be coördinated at infinity or, maybe, converged at a near object below the median plane), nevertheless, the *force*, which compels the holding of the eyes in their coördination state, or, in other words, prevents any inhibitory action on the part of these muscles, for the binocular single vision fusion act, is a psychic one. This particular psychic force is, without a doubt, the sole controller of nearly all the *inhibitory activities* of the extra-bulbar muscles.

In the whole realm of ocular motility we have likewise learned *clinically* to recognize and differentiate between four characteristically different inhibitory reflexes of these muscles, thus:

Function of rotations	(1) Passively resistant inhibitions. (Normal)
Function of coördination	(2) Quasi-passive resistant inhibitions. (Abnormal) (3) Tonically-resistant inhibitions. (Normal) (4) Clonically-resistant inhibitions. (Complexly abnormal)

The first, or the *passively resistant inhibitions*, are found in the associated rotational movements of both eyes in orthophoria and, likewise, in the associated rotational movements of heterophoric eyes.

The second, or the *quasi-passive resistant inhibitions*, are found in the coördination function of *manifest true heterophoria*.

The third, or *tonically-resistant inhibitions*, are found in the coördination function of *true orthophoria*.

The fourth, or *clonically-resistant inhibitions*, are always found in latent, or *spastic heterophoria*.

In illustration of the first, we need only to recollect that the main import of the function of the binocular rotational

movements is to direct the visual axes (or the visual regard) to the spacial location of any object, the undefined image of which primarily falls upon a portion of the retinal field outside of the macular fusion region.

Since such rotational movements are accomplished by a sort of rhythmic or simultaneous contraction and relaxation of certain extra-bulbar muscles which affect the particular direction of the rotational movement, and, also, while the eyes are engaged in any kind of rotational movement, the fusion force, for the time being, must relax its domination over all the rotational inhibitory reflexes (because during the interval of such ocular rotational movements the sense of vision is practically limited to undefined perceptions of surrounding objects without due regard to the interest of fusion), therefore, this kind of inhibitory reflexes—*i. e.*, the muscular relaxation or inhibition activities as they are affected during the binocularly associated rotational act, but have no part in the fusional coördination function—we designated as *passively resistant inhibitions.*

We have considered the nature of the inhibitory activities of the extra-bulbar muscles as they are related to the binocular associate rotational movements in order to more substantially prove our premise (2), as set out in the beginning of the discussion under the main title of the subject, namely, *true heterophoria has no relation to and therefore is not* (*in a diagnostic sense*) *found*, *or uncovered*, *in the function of the rotational movements of the eyeballs.* (Vide *American Journal of Physiological Optics*, Vol. IV, p. 60-76, 1923.) Eliminating thusly the preceding element as a causative factor, we then became firm in the belief that heterophoria is *in toto* an anomaly clinically found only in the function of the ocular coördination. This coördination function, if it is to act normally, we likewise believe is greatly dependent upon: (1) A very perfect alignment of the extra-bulbar muscles, (2) a normal and unobstructed influx of innervational influence to these muscles, and (3) of most im-

portance, a normally developed psychic fusion impulse. Being possessed of the three attributes enumerated above, binocular coördination is then normal, or, as we choose to call it, innervationally synergistic; and then, together with normally acting refractive components, the performance of the function of binocular single vision becomes long enduring, comfortable, and a very easy matter.

Because we are principally concerned in the treatment of the subject of heterophoria, and also because we claim that heterophoria, to be recognized as an oculo-motor anomaly quite distinct from any other oculo-motor derangement, must first of all be concomitant with a practically normal function of binocular associate rotational movements, therefore, it becomes evident that any pair of eyes which clinically show an anomalous rotational function become at once disqualified from the distinction of being recognized and treated under the heterophoric order.

Having thus considered (1), the relation of the inhibitory reflexes to the function of the ocular rotations, we shall aim to direct our attention to (2), (3), and (4), the clinical significance of the inhibitory reflexes as they are related to the function of binocular coördination, as outlined in these pages.

Pueblo,
Colorado

[To be continued]

Tetrachromatic Vision and the Genetic Theory of Color*

Christine Ladd-Franklin, A. B., LL. D.

IT would seem to be time for the poor children in the kindergarten to be taught that the number of different "colors" in the spectrum (and in the whole world of natural objects as well) is not seven, nor six, but simply four—red, yellow, green and blue. We have been told lately by Dr. Jennings, in the *American Journal of Physiological Optics*, that the number is seven, and by U. S. Public Health Bulletin No. 92 (prepared by direction of the Surgeon General) that the number is six. The Milton Bradley Company, which furnishes countless delightful kindergarten objects for the children, follows the customary delusion that there are six. But every psychologist knows by this time, thanks to the life-long labors of Hering, that the number of different chromatic sensations (chromata) furnished by the spectrum, and by all of nature, too, is four. No physicist, however, is as yet aware that there are more than three; I am in the habit of saying that the physicists are all psychically blind to both yellow and white, all save one, Professor Robert Wood, who in his *Physical Optics* explicitly recognizes the existence of a "subjective" yellow.[1] In course of time, no doubt, even the physicists will recognize the fact that *all* the color sensations are "subjective"—that there are no reds, greens, etc., in the extra-corporeal world, but that there are simply the erythrogenic, xanthogenic, chlorogenic and cyanogenic light rays—and that any ray-combination that looks white (as, for instance, a mixture

* Published in this *Journal* through the courtesy of the author and of Dr. J. McKeen Cattell, editor of *Science*, together with revisions and additions made by the author in September 1923.

[1] Mr. Luckiesh is a second exception.

of "yellow" and "blue" light) is a leucogenic combination and due to a "leuco-base."

The reason that led Newton to find seven colors in the spectrum was an aesthetic one—the spectrum is, counted in wave-lengths, about an octave long; in the music octave we recognize seven notes, so why not assign seven tones also to the color octave? In this way what was common knowledge in regard to the number of colors in the world from the time of Leonardo da Vinci became vitiated for a hundred and fifty years by an error which it is still hard to recover from. Hering, in opposition to Helmholtz, recognized that there are four chromatic sensations, but he too was led astray by a logico-aesthetic consideration; he thought it would be nice if, since red and green are, like blue and yellow, a "disappearing" color pair, they were also a white-constitutive color pair. So he said we will assume that they *are* a white-constitutive color pair, and to make the situation still more pleasing we will assume that black and white too are at least a disappearing color pair. But I have shown that when you take the exact red and green (or, in fact, anything near them) you get, on mixing, not white but yellow. My contention on this point has been accepted by Westphal, by v. Kries and others; the colors which are complementary, or white-constitutive, are, as Titchener, with a degree of honesty which is unusual in the followers of Hering, admits, not red and green, but crimson and verdigris—in other words, white is here, as elsewhere, made out of red, green *and blue.*

Normal, mid-retinal, vision is tetrachromatic. It is to be hoped that we may sometime persuade the Milton Bradley people (whose red, green, yellow and blue papers are, as I have shown, very near to the exact, unitary, Red, Green, Yellow and Blue—I write these color-names with capitals when the colors are exact), and the United States government as well, that the *different* colors in the spectrum are four in number, and that if one adds to one's papers two of the dual

color-blends, red-blue and red-yellow (the so-called purple and orange), one should add also the remaining dual color-blends, green-blue and green-yellow. (The fact that these last two color-blends have no misleading unitary names is so much to the good.) Attention should be called at the same time to the curious fact that though you may easily have the *physical* conditions (the proper light-ray mixtures) for the two other possible dual color-blends (the red-greens and the yellow-blues), these are *sensations* that never occur—their places are taken, respectively, by yellow and by white.

I should like to point out that the color theory which I have proposed (the evolution color theory) is the only one in existence which holds together (the function of a theory), and makes reasonable, the three fundamental color-sensation facts (and the other, subsidiary, facts as well). These are:

A. The Helmholtz fact: the basis of color-vision is a *three-receptor* (chemical) process,—the "red," "green" and "blue" light-rays *are sufficient* (on mixing) to reproduce the whole gamut of the color sensations.

B. *Nevertheless* (the Hering fact) yellow and white are also unitary sensations and not any sort of sensational color blends, although they may be produced by physical light-ray mixtures. Hering thus corrects what I have called the psychical color-blindness (to yellow and to white) of the Helmholtz school, but at the cost of concealing from his followers all the facts which are mapped out in the Helmholtz triangle, or what the metallographers call when they make a diagram of their ternary alloys—a less frightening word perhaps—the "triaxial diagram." The color-triangle, in other words, is nothing more than the representation of mixed color-constitution in terms of trilinear coördinates; what could be more natural when the variables which are both sufficient and indispensable are three in number?

C. Of equal importance is the fact of the order of phylo-

genetic development of the light-sensations (achromatic and chromatic). It is, in its three successive stages, as has been perfectly well made out, this:

1 A white-sense only, achromatic vision (furnished by the more primitive retinal elements, the rods), which occurs (a) in the lower animals, such as lived, for instance, in carboniferous times (when colored flowers and colored birds did not yet exist),[1] (b) in those defective individuals who have achromatic vision only, and (c) in the far periphery of our own retina.

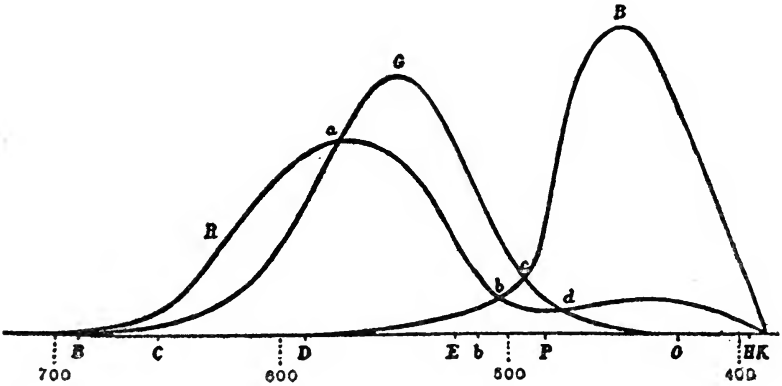

Fig. 1. R, G, and B, distribution curves. These are the curves of König and Dieterici corrected to new determinations of the points of section, *a*, *b*, *c*, *d*. Abscissae, wave-lengths of the interference spectrum of the arc light; ordinates, arbitary scale. (F. Exner.)

2 Dichromatic vision—the spectrum is yellow at one end, blue at the other (but in place of what should be the yellow-blues appears white). This is the vision (a) of the bees (v. Frisch), (b) of the partially color-blind, and (c) of our own mid-periphery.

3 Complete, tetrachromatic, color-vision,—the red and green sensations have been added; but where we have the

[1]We have no means of knowing whether our own background sensation, the non-light sensation, that of blackness (which exists for the purpose of filling up our visual field), came in with the first, non-specific, light-sensations, or only later. There is some ground for thinking it arose later. I discuss this question in my article on "*The Sensation of Blackness.*"

physical conditions for seeing the red-greens, or the red-green-blues, *yellow* and *white*, respectively, take their places.

The theory of Helmholtz is (as Professor Cattell has well said) both pre-psychological and pre-evolutionary. That of Hering (besides being otherwise impossible) is pre-evolutionary: there is no question that red and green (which *revert* to yellow) are *developed out of* yellow. But worse than this—each of these theories is utterly contradictory to the facts which the other theory is expressly built up upon. This circumstance has not hitherto been sufficiently noticed: thus Mr. Troland says (*The Enigma of Color Vision*)*: "The Young-Helmholtz theory is preferred by physicists because it lays emphasis primarily upon the stimuli to vision, while the Hering theory receives more attention at the hands of the psychologists because its fundamental conceptions are

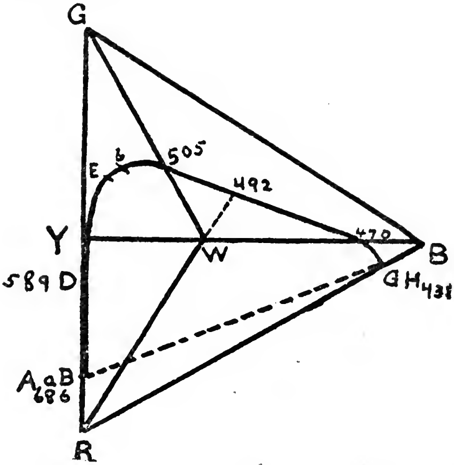

Fig. 2. The color triangle, which exhibits "matching by mixture."

derived from introspective analysis." This is true, but it is very far from being an adequate account of the situation. (1) The Young-Helmholtz school not only assumes but

* *American Journal of Physiological Optics*, 1920 and 1921.

proves (not, as is often said, by means of the König-Dieterici spectral distribution curves by themselves, but by the complete coincidence of these curves with those, respectively, of the two types of yellow-and-blue vision)[1] that the number of "primary" colors is *three* and not four. (Fig. 1). This is fact. (2) The Hering school has only to ask for the most cursory examination of the gamut of color-sensations to show that the number of its different chromatic constituents is four, not three. This is fact. But the group of facts subsumed under (1)—the facts of "matching by mixture" (Fig. 2)—is absolutely incompatible with the theory of Hering,[2] and the group of facts subsumed under (2) is absolutely incompatible with the theory of Helmholtz. It is little to the credit of any association of scientists that they still solemnly discuss the theories of Helmholtz and of Hering. The situation is simple: each of these theories is absolutely refuted by the *facts* which are the ground-work of the other.

I have devised a simple diagram by means of which one can keep in mind the impossibility at once of the Helmholtz and of the Hering theory. Color diagrams are immensely more illuminating if they are done up in color.[3] But lacking that, one can make-shift with appropriately striated surfaces. I call this diagram my Quadrigeminal Color Area (a term suggested by the *corpora quadrigemina*), but it is at the same time triaxial. (The triangle should always be drawn with the Y B line a horizontal (fundamental) line, as indicative of the fact that yellow and blue were developed first—that red and green were a later addition. The actual spectral line approaches nearer to the point W in

[1] *Dictionary of Philosophy and Psychology*, Art Vision, II, 788.

[2] The attempt of v. Kries to supplement the Helmholtz theory by supposing that the three colors resolve themselves into four at a higher level of the visual nerve system is a purely *ad hoc* hypothesis, and without significance. See my articles on "The Theory of Color Theories," *Comptes rendus du VIe Congres intern. de Psychologie*, Genève, 1909, and *Psychological Review*, May 1922.

[3] Stoelting is putting on the market for me my complete set of colored color-diagrams.

the green region on account of the fact that the three chroma[1] curves overlap here, as is represented in Fig. 1.)

This figure illustrates the fact that while the color field is a function of three variables, when you reproduce it by the mixing of specific lights, you no sooner look at it than you see that it consists of *four* distinct regions—the whitish yellow greens, the reddish bluish whites, etc. It suffices to upset at once the two "antiquated" (as they call them at the University of Chicago) current theories. I make the yellow circle small to indicate: (a) that yellow occupies a very narrow region in the spectrum, (b) that it is the result of a secondary retinal process, and (c) that it has been for a hundred years invisible to the physicists. It is this color curve, representing facts and not imaginations (as do the color-curves of Hering), which should, of course, always be drawn as the belt-section of the color-pyramid.

To meet the difficulties of these antiquated theories I have devised a theory (the genetic theory) "which takes into account both sets of fundamental facts which the other theories were respectively devised to explain," facts which do however in reality collectively refute them both. (You will not find even a picture of the color triangle in any of the writings of the followers of Hering.) It is a perfectly simple theory (the theory of Hering is far from simple—see Parsons, p. 673), and it is wholly in line with the most recent conceptions of the chemists—Harkins, Bohr, Soddy, Rutherford (who are now engaged in working out the evolution of the atoms), Mathews, Willstätter (chlorophyll and haemoglobin, Bayliss, p. 252) and many others. This theory has been pronounced to be unobjectionable by the chemists, and it is now practically accepted by most of the psychologists.

The theory in brief is this:

There is probably no other organ in the body in which

[1]I have been constantly urging, since 1913, the use of the word *chroma* (plural, *chromata*) to obviate the shocking ambiguity in the present meaning of "color." From this follow, of course, chromaticity (instead of saturation), achroma, and achromaticity (instead of degree of non-saturation).

the record of development has been preserved in such a remarkable fashion as in the organ of vision. We have, *pari passu* with the successive stages of specificity of response to the visual spectrum, represented in Fig. 4, (1) an anatomical development of rods into cones, and (2) a chemical

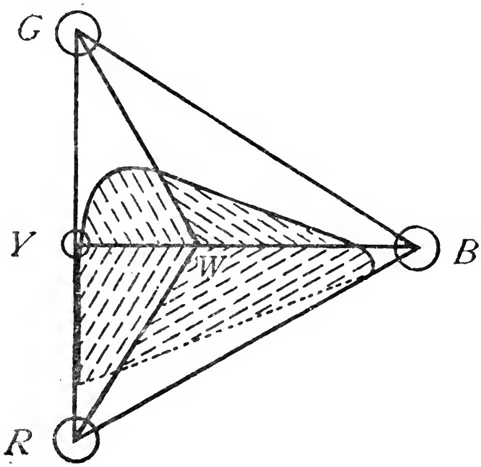

Fig. 3. The *quadrigeminal* color area—*triangular* in shape.

development of the rod-pigment sensitizer such that in man only there is an intermediate stage, the visual yellow, between the "visual purple" and the final leuco-base (König, Garten). What more natural than to suppose that there has been also a development of the light-sensitive receptor substance in the receptor organs (rods and cones) of the retina? This developing substance must, however, be at the same time of such a nature as to account for the singular fact (unknown in any other region of sense) that the colors successively developed are disappearing color pairs—they produce a more primitive white, or yellow (see above). If these facts are held distinctly in mind, the appropriate chemical conception almost forms itself. I represent, purely diagrammatically, of course (Burdon-Sanderson[1] especially

[1]Presidential Address, British Association, *Nature*, Vol. 48, p. 469.

noted this point when my theory first came out) that portion of a molecule which is capable of being dissociated out of light in the way indicated in Figure 5. The development

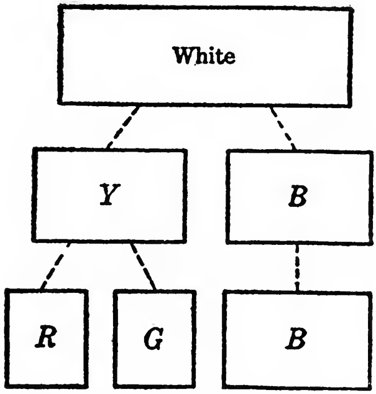

Fig. 4. Stages 1, 2 and 3 of the actual development of the color sense.

required is that of a greater and greater *specificity* to the electro-magnetic vibrations of the visible spectrum. A portion of a molecule which at first is broken off indifferently by the whole spectrum becomes in a second stage more specific—by a fresh segregation of atoms a portion Y responds to the yellow end of the spectrum, a portion B to the blue end of the spectrum. But what happens when yellow and blue light fall at once on this chemical substance? The *Y* and the *B* (since they are the chemical constituents of W, because the assumption is that they were segregated out of it) will chemically unite and will produce W, the nerve-excitant of the sensation white. In the same way in the third, and latest, stage, the newly segregated *R* and *G*, when torn off from the molecule by light of low and of high-middle frequency, will revert to the mother substance *Y;* and if light of high frequency, "blue," is now added, we shall again have the nerve-excitant of white. That is to say, just as when we have in a test-tube the chemical constituents

of HCl (namely, H and Cl) they chemically unite, under proper conditions and produce HCl, so in a cone we have

$$R+G=Y$$

$$Y+B=(R+G+B)=W$$

Observe that we have now, quite incidentally, explained how it happens that lights of only *three* specific, homogeneous wave-lengths ("red," "green" and "blue") are sufficient to reproduce the whole gamut of color sensations, including yellow and white, which the physicists have never noticed the existence of.[1] Yellow is a secondary product, and so is white, but they are both perfectly good unitary sensations. The theory explains at the same time, of course, how it is that the primitive white mediated by the rods is the same sensation as the white made out of (in the highly developed

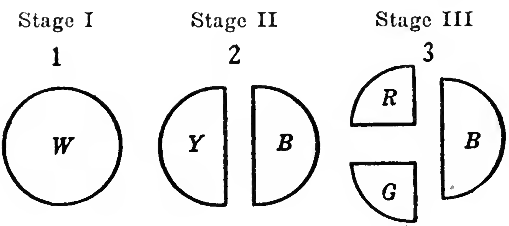

Fig. 5. "The cleavage products in the three stages of the color sense. This diagram does not represent the entire light-sensitive molecule, but only the specific cleavage products which, according to the Ladd-Franklin theory, constitute the several nerve excitants for the color sensations" (From Woodworth's *Psychology*). For other diagrams, see *Psychological Review*, 23: 247, 1916; *Zeitschrift f. Psychologie*, Bd. 6, etc.

[1]Crowther, a prominent English physicist, actually says that the white produced by mixing homogeneous yellow and blue light-rays is not a "real" white—that, he thinks, *must* be a whole-spectrum white. Professor Titchener, on the other hand, has called my attention to the fact that on my view white is *always* (aside from the most primitive stage) due to a union of yellow and blue constituents—red and green first unite to produce yellow and that then unites with blue to produce white. Thus in the case of that admirable chemical analogy that has been found for me by Dr. Acree—a dye-stuff, rosaniline carboxylate—three cleavage products, say A, B, C, are such that A and B, and A and C, form mixtures, but B and C form a chemical compound, and when that has once been formed it chemically unites with A and forms the chemical compound ABC—in this case an ethyl chloride.

cones) yellow and blue, or red and green and blue. There is no reason, of course, as Professor Carr has pointed out to me, why there should not be also some of the more primitive chemical substances in the cones of the central retina.

Since the interesting work of Hecht, it seems to be quite certain that the first effect of light on the retina is photo-chemical. It is here, without question, that is found that "transformer mechanism," as I have called it, by which what should look to us like 165 *different* colors in the spectrum is replaced by a paltry four—the best that Nature could accomplish with only one small cone to work in. Five unitary colors (including white) and mixtures of them—the color blends—are all that we can see in the 30,000 *discriminable* sensations that are given us by light. It is nerve impulses produced by retinal chemical stimuli of the character which I have described (or of some other character) that mediate the processes which take part in the final "neuro-psychic correlation"—a term which I have proposed as much preferable to psychophysical parallelism in the domain of color.

In a recent discussion of my color theory (*American Journal of Physiological Optics*, 1920-21) it is maintained that it would be more "advanced" to regard as of "prime importance" the cortical processes: "It appears to me that the Ladd-Franklin theory postulates the existence in the retina of conditions of sensation of the sort required for the processes in the cerebral cortex which directly underlie the visual consciousness, but which are not required and probably do not exist in the case of the retina." In reply to this it is only necessary to point out that if a "mechanism of defect" (such as would result in loss of consciousness for the red-greens and the yellow-blues) is found to occur in any part of the light-sensation chain (rods and cones, bipolar cells, third neurons, corpora quadrigemina, optic thalamus, cortex) that defect cannot be recovered from in any one of the later stations of the nerve impulse—if R and G have once reverted into Y, and Y and B into W, anywhere in the visual

circuit, it is not necessary to provide for their doing it again in the cortex; on the other hand, if this defect has *not* happened lower down—if a separate "blue" and "yellow" have successfully reached the cortex—it is improbable that Nature, out of pure *Bösartigkeit*, should have introduced in the cortex a mechanism for their extinction.[1]

v. Kries has objected that in my theory it is not explained how the same sensation of whiteness should be mediated directly in the rods, and in the more highly developed cones out of a physical mixture of red, green, and blue lights, but, as I have pointed out above, this is exactly what my theory does explain.

It has been called to my attention that several of the psychologists, while practically adopting my theory of color sensation, express the opinion that I have given no explanation of the sensation of black. But that is not the case; I have not, it is true, discussed black very frequently, and that, I believe, for two reasons. (1) It is very simple—it has no connections with any other of the color-sensations. The reason that color "theory" is so important, and has been so contended over, is that the facts of color (excluding black) are so very mysterious: why do we fail to see the yellow-blues and the red-greens, and why do we get, respectively, *white* and *yellow* in their place?[2] Blackness stands by itself—it has no such queer relations with any of the other colors. Black and white, for instance, are *not* a dis-

[1]I discuss this point more fully in the *Psychological Review*, May, 1922.

[2]No explanation of this recurrence of a primitive *yellow* and *white* has ever been given save that which I have outlined above (See Fig. 5). In fact, the evolution of the color-sense has been wholly neglected by the makers of the color theories. It turns out, however, to be the most illuminating of all the intricate phenomena involved; by combining it with the two well-known, but hitherto antagonistic facts—that vision is a tri-receptor initial process (Helmholtz) and that it nevertheless ends in a tetrachromatic sensation gamut (Hering)—sufficient light is thrown on the situation to clear up the whole enigma of color. To that clearing up, as Mr. Troland has said, with great acuteness, this conception of mine is probably indispensable: by it is effected what might be called, in the language of Hegel, a "higher synthesis" of (1) the Helmholtz fact, (2) the Hering fact, and (3) the actual course of development—both phylogenetic and ontogenetic—of the color sense.

appearing color pair; they give us the series of black-whites, or greys. Black, being a sensation attached to zero stimulation—not a light sensation but a non-light sensation—is naturally (since zero has one value only) a sensation of only one degree of subjective intensity; the series of greys comes from changing the subjective intensity of their white constituent only. A blue-green of a given proportion of blueness and greenness we can see in dozens of different intensities; not so a grey. Give a certain grey a higher illumination and you change the quality as well as the brightness of your black-white blend. Professor G. E. Müller has dwelt upon this latter fact, but he has given a wrong interpretation of it; Wundt, however, although his theory of color is negligible (and has been neglected), puts this situation correctly. It is easily accounted for on my theory; it is a sensation attached, in the final neuro-psychic correlation, to a non-stimulated condition of the cortex. But *why we have* a sensation of blackness is something which I have explained elsewhere.

A fuller account of the Genetic Theory of Color Sensation will be found in most of the recent books on psychology—as Calkins, Judd, Angell, Breese, Watson, Warren and Woodworth. I have discussed it also in the *Psychological Review*, 23, 1916, and 29, 1922; in the *American Cyclopedia of Ophthalmology*, 1913; in the *Dictionary of Philosophy and Psychology;* in *Mind*, 1892, 1893, and in *Science*, 22, pp. 18-19. In the last two places I have discussed its fundamental difference from the theory of Donders. My theory has been taken over by Schenck without due acknowledgment, as has been pointed out for me by v. Brücke (*Zentralblätter für Physiologie*, 1905). It has suffered from not having been criticized enough; some criticism of it by v. Krise and by Troland I have discussed very fully in *Practical Logic and Color Theories* (*Psychological Review*, *May*, 1922).

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Editorials

The Editor and the Publishers of the *American Journal of Physiological Optics* do not hold themselves responsible for the opinions expressed by the various contributors. From time to time there are articles, appearing in this *Journal*, with which the Editor and doubtless many readers cannot agree, either in whole or in part, as to the methods pursued or the conclusions reached. Such articles are printed in the hope that they will stimulate further investigation and research. The great discoveries in the scientific world have been made by men and women who have had the courage to depart from the "beaten path." "Herd thinking" is rarely conducive to "creative thinking." This is the spirit in which the articles in each and every issue of this *Journal* are presented to the readers.

Louis Pasteur (1822-1895)

"Travailler, travailler toujours"

ON the 27th of December a hundred years ago there was born at Dôle, Franche-Comté, Louis Pasteur,[1] destined to become one of the world's greatest biological chemists and a contributor of investigations to the field of preventive and curative medicine that will immortalize his name to all generations. In so far as we can learn, he made no contributions to the field of physiological optics and therefore it might seem to some who read these pages as though we had gone far afield in penning these words upon the life and work of one whose labors were quite remote, to say the least, from the purposes and character of this *Journal*. But we feel, since the direct and practical applications of the laws and fundamental principles of physiologic optics have to do with the alleviation and remedying of visual defects—and the eyes are but a part of the human body, *i. e.*, sanctified mud —that we can pause long enough in the pursuit of those

[1] The facts quoted in this editorial are taken from the *Encyclopedia Britannica*.

things which chiefly concern us to pay tribute to the memory of one who did so much to revolutionize surgical practice and to stay the effects of certain dire diseases in both man and beast. And perhaps, too, we should say that the success of another, attained by years of unselfish labor—*travailler, travailler toujours*—in any field of scientific endeavor, brings us back to the realization of the fact that it is worth each man's while to keep plodding away at the unsolved problems which lie in his pathway.

Pasteur, it is recorded, was not a remarkable student, and in Pasteur's diploma it is recorded that he was only mediocre in chemistry. In his early years and early trials the dominant note of his life was sounded, for he wrote his sisters: "There are three things which constitute the whole of human life—the will to do something, the engaging in the work and labor necessary, and the culmination and final success. The will and power of mind open the way to brilliant and happy careers, work enables one to surmount the difficulties, and ultimately success crowns the laborer and his efforts."[1]

The young chemist from Franche-Comté won his first honors by the solution of a problem in isomerism—now well known to chemists, but which baffled the greatest chemists and physicists of the time. The long and patient observations needed in this work prepared him well for undertaking the solution of the difference between sound and unsound beer. "Pasteur one day visited a brewery containing both sound and unsound beer. He examined the yeasts under the microscope and at once saw that the globules from the sound beer were nearly spherical, whilst those from the sour beer were elongated; and this led him to a discovery, the consequences of which have revolutionized chemical as well as biological science, inasmuch as it was he beginning of that wonderful series of experimental researches in which he proved conclusively that the notion of spontaneous gener-

[1]Translated freely from the original French.

ation is a chimera. Up to this time the phenomenon of fermentation was considered strange and obscure. Explanations had been offered by Berzilius and Liebig, but they lacked experimental foundation. This was given in the most complete degree by Pasteur. For he proved that the various changes occurring in the several processes of fermentation are invariably due to the presence and growth of minute organisms called ferments. Brewer's wort remains unchanged for years, milk keeps premanently sweet, and these and other complex liquids remain unaltered when freely exposed to air from which all these minute organisms are removed."

Why does any substance, like milk, become sour on exposure to ordinary air? In a series of most delicate and intricate experimental researches Pasteur proved that when the atmospheric germs are absolutely excluded no changes take place. "In the interior of the grape, in the healthy blood, no such germs exist; crush the grape, wound the flesh, and expose them to ordinary air, then changes, either fermentative or putrefactive, run their course." Crush the fruit or bruise the flesh and put them under conditions which preclude the presence or destroy the life of the germ, and no changes take place. The application of these facts to surgical operations, in the able hands of Lord Lister, was productive of the most beneficient results, and has revolutionized surgical practice.

As Pasteur said: "There is no greater charm for the investigator than to make new discoveries; but his pleasure is heightened when he sees that they have a direct application to practical life." In this day and age, however, we find far too many who decry anything and everything that does not appear to be immediately "practical." And by this word "impractical" they really mean that it cannot be at once turned into dollars and cents through "spontaneous generation." Pasteur proved conclusively that "the notion of spontaneous generation is a chimera"—a biological prin-

ciple just as applicable to the world of business and the realms of professional interests as in biology. It was a long way indeed from the early experiments of Pasteur on isomerism and the souring of wine to the discovery of the cause and cure for hydrophobia, and the establishment of the Institut Pasteur. And yet the first was necessary in order that the others might follow. No field of science can expand unless it has its natural born investigators who love to dig into its problems for the sake of searching out the unknown. And mankind in general cannot benefit from many of these elaborate and, in many cases, intricate experiments unless others, with a little different slant in their investigational turn of mind, put them into workable and serviceable form. And the division line between the so-called theoretical and practical is often measured by a hair's breadth, for the reason that the theoretical always contains in essentials the gist of its practical side. We need more *theorists* in the field of physiological optics and we must look for new developments away from the beaten path.

At any rate, Pasteur had the good fortune and just reward of seeing the results of his work applied to the benefit both of the human race and of the animal world. "Just as each kind of fermentation possesses a definite organized ferment, so many diseases are dependent on the presence of a definite microbe; and just as the gardener can pick out and grow a green plant or vegetable, so the bacteriologist can (in most cases) eliminate the adventitious and grow the special organism—in other words, can obtain a pure cultivation which has the power of bringing about the special disease. But by a process of successive and continued artificial cultures under different conditions, the virus of the organism is found to become attenuated; and when this weakened virus is administered, the animal is rendered immune against further attacks. The first disease investigated by Pasteur was that of chicken cholera, an epidemic which destroyed ten per cent of the French fowls; after the application of the

preventive method the death-rate was reduced to one per cent. Next came the successful attempt to deal with the fatal cattle scourge known as anthrax. . . . As to the money value of these discoveries, T. H. Huxley gave it as his opinion that it was sufficient to cover the cost of the war indemnity paid by France to Germany in 1870."

At the inauguration of the Institut Pasteur in 1888 in Paris, Pasteur closed his oration with the following words:—"Two opposing laws seem to me now in contest. The one, a law of blood and death, opening out each day new modes of destruction, forces nations to be always ready for the battle. The other, a law of peace, work and health, whose only aim is to deliver man from the calamities which beset him. The one seeks violent conquests, the other the relief of mankind. The one places a single life above all victories, the other sacrifices hundreds of thousands of lives to the ambition of a single individual. The law of which we are the instruments strives even through the carnage to cure the wounds due to the law of war. Treatment by our antiseptic methods may preserve the lives of thousands of soldiers. Which of these two laws will prevail, God only knows. But of this we may be sure, that science, in obeying the law of humanity, will always labor to enlarge the frontiers of life."

So Pasteur, rich in years and in honors, simple-minded and affectionate as a child, passed on to be numbered with his forefathers, leaving a name to be added to the galaxy of those who have labored "to enlarge the frontiers of life."

Perhaps, as Robinson says in his book on *The Mind in the Making*, "we accept our breakfasts, our trains and telephones, and orchestras and movies, our national constitutions, or moral code and standards of manners, with the simplicity of a pet rabbit," and it is doubtless true that we have absolutely inexhaustible capacities for approximating what others do for us with no thought of a "thank you." So we of the present generation, blessed with so much that has been given to us as an enlargement of the frontiers of life, cease

long enough to say "thank you," and to write our word of thanksgiving that Louis Pasteur lived, and, as he lived, labored. Even in the hour of death he labored; for it is said that he turned to the devoted pupils who watched over their master's last hours, and exclaimed: "Ou en êtes-vous?" "Que faites-vous?" and ended by repeating his favorite words, "Il faut travailler." The doctrine of labor and of service, both in theory and in practice, by word of mouth and by actual deed, needs to be an integral part of every man's life. It is one of the greatest, most worth-while things in life after all— to "labor and to wait."

Orthophoria and Ocular Vergence

A Consideration of Matters Pertaining to Their Definition and Determination

FROM time to time questions arise as to the true significance and the real findings when muscle imbalance tests are made, for example, at twenty feet, or again at ten feet. The definition of orthophoria laid down by Stevens is that orthophoria is a "tending of the visual lines in parallelism, the determination being made for a point not less than six meters distant," while heterophoria is a "tending of these lines in some other way, the determination being made for a distant point as above indicated." There is some question, however, as to whether orthophoria or small amounts of exophoria and esophoria are correctly determined in the customary tests in vogue. It is frequently asserted that, with a fixation light or object at six meters and the Maddox rod horizontal—hence giving a vertical streak or band of light—parallelism of the visual axes is indicated if the streak passes through the light and that, therefore, orthophoria exists. It appears to the writer that this may or may not be so.

Again, it is stated that binocular fixation of the light signifies a convergence of one-half degree, and that, "to obtain the true deviation from parallelism, we must in exophoria deduct one-half from, and in esophoria add one-half degree to, the number of degrees indicated on the scale." Again, we may raise the question of doubt.

And still again, we find the statement recorded that when, in the Maddox rod test at six meters (twenty feet), the vertical streak cuts the light and so indicates what is commonly regarded as orthophoria, "the condition is not that of orthophoria but one of 0.16 meter-angle of esophoria, and that, if there be true orthophoria, the test at six meters would show 0.16 meter-angle of exophoria." Roughly

speaking, the meter-angle for each eye is 1° 45′ or about 3Δ, hence the binocular meter-angle, which must be involved in binocular single vision, is practically 3 degrees of actual turning or optically equivalent to the deviation of parallel light rays produced by a 6Δ. And again we feel that these statements may or may not be correct.

Presence or Absence of Accommodation

Any discussion upon this matter of orthophoria and heterophoria, their definitions and the true interpretation of any particular set of findings in any given case, immediately brings up the question of the relationship between accommodation and convergence. For if accommodation is operative in any tests made upon the extrinsic muscles, there may or there may not be any accompanying convergence—commonly referred to as accommodative convergence—and as a result there is a question as to what should be considered orthophoria or the reverse. It is possible, for instance, that the act of binocular single vision may be accomplished wholly through accommodative convergence, or wholly through supplementary or fusional convergence, or again partially through one and partially through the other. The last named *modus operandi* we believe to be existent in about seventy per cent of our cases.

Disagreement of Data by Various Methods

The question immediately arises as to whether or not all of our various tests for so-called orthophoria or heterophoria, in so far as the lateral extrinsic muscles are concerned, stimulate the same amount or a different amount or again a total suppression of the element of accommodation. The writer has been at work for some little time upon the problem of collecting and coördinating data upon the status of the extrinsic muscle balance in cases in which the following methods were pursued:—(1) The ordinary Maddox rod test, (2) dissociation with a 6Δ, base up or

down, before one eye, (3) dissociation by means of the Maddox double prism, and (4) the use of the screen or cover test in conjunction with the Maddox rod. He wishes to, at this time, simply record the fact that these different methods do not give the same findings with fixation at any given distance—as for example, 20 feet—and that in general less exophoria is indicated by the first than by the other three methods. This would tend to show that the classic Maddox rod test involves either a greater stimulus to accommodation or else permits the fusional convergence to enter—a state of affairs which should be eliminated. Or, to state it in other terms, it is possible that the last three methods may be either less stimulating to accommodation or more suppressive to the act of fusion through the channels of the supplementary fusion centers.

It is a question in the writer's mind, therefore, as to whether or not any strictly accurate deductions as to a condition of orthophoria at distance can be deduced by any method of testing at twenty or thirty feet, unless such data are taken and coördinated with data obtained at other points of testing. We hope to substantiate this point and to make clear our line of reasoning in that which follows, willingly admitting that there may be flaws in the argument which others may discover.

Accommodation in Customary Distance Tests

In the first place, then, it is to be noted that twenty feet, the common testing distance, is not infinity. Light diverging from a twenty-foot distant point has an ocular conjugate which is not exactly at the principal focus of an emmetropic eye, but at a conjugate point slightly behind the retina. This divergence of the light is 1/6 diopter and hence that amount of accommodation has to be brought into action by an emmetrope so that the light may be focussed at the retina. Therefore, a hyperopic eye has to exert 1/6 D. more accommodation than the amount of

hyperopia present and the emmetropic eye without accommodation is myopic 1/6 diopter. These facts are of significance in tonicity or extrinsic ocular muscle tests with fixation at the 20-foot distance for the reason that, should the stimulus to convergence accompany the act of accommodation, we shall have a tonicity test which would differ from that obtained if there is no accommodative convergence. Under complete cycloplegia the element of accommodation will be allayed and the accommodative convergence would presumably be annulled, unless perchance the dominance of the mind, taking cognizance of the distance of the fixation object, should cause the old association of convergence with accommodation to be operative. In such tests as these we are discussing it does not appear to the writer to be as scientific a procedure to determine the static vergence under cycloplegia as under conditions in which the findings, that presumably render the eyes as nearly emmetropic as possible, are worn, for the reason that we are desirous of determining the *status quo* of a pair of eyes under normal or workaday conditions.

Meter-Angles and Prism Dioptries of Convergence

Turning for the moment from this consideration of the accommodation involved in our ordinary testing distance of 20 feet to the matter of the amount of convergence actually involved in binocular single vision at any specified point, we note, first of all, that the term meter-angle is both inaccurate and used with a double meaning in text-books. For the meter-angle depends upon the interpupillary distance in stating its exact value in degrees of actual turning of the eyes. And again, the meter-angle of Nagel is not formed by the intersection of the two visual axes, but is the angle formed by the intersection of one visual axis with the extended median plane of the head, the head being

in the primary position and the point of fixation being at a distance of one meter. Hence, under this definition or statement, the angle formed by the visual axis of the other eye and the extended median plane of the head is also a meter-angle; the one being exactly equal to the other by definition. The sum of the two angles constitutes the angle of convergence, so that the angle of convergence is twice the meter-angle of Nagel.

We believe, then, that less confusion would arise if all considerations of meter-angles were abolished from the literature. If this should not be possible, then it would seem highly desirable to define the meter-angle as being the angle formed by the intersection of the visual axes at one meter. Consider, for instance, the statements made in the second and third paragraphs of this article in which it is stated: (1) "To obtain the true deviation from parallelism we must in exophoria deduct 1/2° from, and in esophoria add 1/2° to, the number of degrees on the scale," and (2) "What is commonly regarded as orthophoria is not that of orthophoria but one of 0.16 meter angle of esophoria." It is difficult to say in (1) whether angles or prism degrees are referred to; if in prism units we believe it should be twice as great as it is, and in (2) we are left with a mathematical quantity defined in a variable unit, since the interpupillary distance is variable, being on the average about 64 mm.

This point was, however, so admirably and simply cleared up some years ago by Charles F. Prentice that we are at a loss to understand why any other unit than that of the prism-dioptry is employed in the literature of today. Having defined the prism-dioptry as that power of prism which will cause a deflection or deviation of one centimeter at one meter, Prentice laid down the following important principle (*Ophthalmic Lenses*, 1907, page 114): "Read the patient's interpupillary distance in centimeters, when half of it will indicate the prism-dioptries required to substitute

one meter-angle for each eye." This statement holds to the definition of the meter-angle as given by Nagel. In finding, however, the total equivalent convergence in prism-dioptries when binocular single vision obtains at one meter distance—or any distance for that matter—we are desirous of knowing the binocular meter-angle. Therefore, to reduce these considerations to their simplest and most usable form, we believe that the best form of statement would be somewhat as follows:—Read the patient's interpupillary distance in centimeters; this quantity will indicate the prism-dioptries required to substitute one binocular meter-angle. This will, therefore, indicate in prism dioptries the amount of convergence required for binocular fixation of a point a meter away. To find the convergence demanded for binocular fixation of a point at any other distance than a meter, multiply the interpupillary distance in centimeters by the dioptral value of the fixation distance. For example, a pair of eyes having a P. D. of 67 mm. and fixing a point 20 inches away will have to converge, in order to have binocular single vision, 6.7 multiplied by 2 or 13.4Δ.

The Determination of Orthophoria

Having laid down these preliminary statements as to the dioptric equivalent of a 20-foot testing distance, or the amount of accommodation demanded of an emmetrope, *i. e.*, 1/6 D., and having reviewed the simplest and most satisfactory method of determining the amount of convergence demanded under any specified conditions of fixation distance and interpupillary distance, we shall take up the question relative to ways and means of determining whether orthophoria or heterophoria exists.

At 20 feet the amount of accommodation involved is 1/6 D. A pair of eyes having an interpupillary distance of 60 mm. will require 1Δ for binocular single vision. Again, at 13 inches, the accommodation demanded is 3 D.

and the convergence needed for binocular fixation is 18 Δ. In either instance cited the ratio of convergence to accommodation is 6 to 1.

If, therefore, convergence should be central, *i. e.*, wholly in association with the act of accommodation, or, in other words, wholly accommodative in source, and if tests are made by methods which demand accommodative action but which wholly eliminate the function of supplementary fusion, we should expect to find the streak and light (Maddox rod test) in conjunction, or the two dots in a row (vertical dissociation prism method), at any and all points. As a result, therefore, such a pair of eyes would be orthophoric according to the established definition of Stevens at 20 feet, 10 feet or any closer point of test, for the reason that the convergence is wholly central or accommodative in character. But we believe that, should orthophoria according to the accepted definition be indicated at 20 feet, we would not be able to say whether or not true orthophoria would exist (theoretically at least) at infinity unless we made tests at other points. Under the data specified above we should say that orthophoria exists at all points from infinity down to the near point of convergence as found in conjunction with accommodation. In such a condition, therefore, tests at 20 and 10 feet would give the same data and the data recorded in either case as to the results of tonicity tests would be that of orthophoria, since the convergence is central.

Let us assume another condition, however, in which tests at 20 feet indicate 1Δ exophoria. Is this a genuine exophoria or should it be considered as indicating orthophoria at infinity? Such a question cannot be answered without supplementary tests at other points. Assuming the same P. D. of 60 mm., and assuming that we obtain data which show 6Δ exophoria at 1 meter and 18Δ exophoria at 33 cm., we are in a position to answer this question we believe and to say that the 1Δ exophoria indicated

by test at 20 feet should be considered as indicating orthophoria at infinity. For evidently in this case there is no accommodative convergence and when binocular single vision is obtained at any specified point of fixation by such a pair of eyes it is wholly through the fusion centers. Calculations by the Prentice rule show that 1Δ convergence is required at 20 feet for binocular single vision, 6Δ at 3 feet and 18Δ at 1 foot. The data assumed to be present in the case cited above show the same amounts of exophoria respectively, indicating quite clearly that convergence in association with the act of accommodation is absent or nil.

We have just cited two instances, in one of which our ordinary tonicity tests at 20 feet show so-called orthophoria which is genuine orthophoria at infinity and in the second of which an exophoric finding at the same distance is indicative of orthophoria at infinity. As a third possibility we cite the case in which a slight amount of esophoria—under or about 1Δ—at the 20-foot fixation distance might be considered as showing orthophoria at infinity. The decision on this point would have to rest upon tests made at other points. If, for example, with 1Δ esophoria at 20 feet fixation and 5Δ esophoria at 1 foot, we might very properly conclude that there was overstimulation of the accommodative convergence due either to subnormal accommodation or possibly to an undercorrection of a case in which the necessary convergence was normally wholly associated with the act of accommodation, no supplementary fusion being demanded. If the first of these conditions exists—as can be readily determined by finding the amplitude of accommodation and comparison made with the normal standard at the given age of the person under test—then, with no accommodation demanded at distance, our slight esophoria at the 20-foot distance might well be regarded as orthophoria at infinity.

As a fourth citation, assume that a person with a P. D. of 64 mm. shows an apparent orthophoria at the 20-

foot test distance and 8Δ exophoria at 13 inches. At 13 inches, following the Prentice rule, 19.2Δ of convergence are necessary for binocular single vision and of this amount 8Δ are finished from the appropriate fusion centers and 11.2Δ are in accompaniment with the act of accommodation. To see distinctly and clearly at 13 inches there are required 3 D. of accommodation. Evidently, then, 11.2Δ out of the 19.2Δ necessary are through the act of accommodative convergence. This means that 11.2/19.2 or roughly 3/5 of the total convergence is associated with the act of accommodation. Is then, the apparent orthophoria at 20 feet orthophoria at infinity? Assuming that the same ratio holds throughout the range of testing distance, then 3/5 of the convergence necessary for single vision at 20 feet (*i. e.*, 1.1Δ), or approximately 0.6Δ, is furnished by the accommodation. An indicated test of orthophoria at 20 feet would, under these circumstances, really disclose, we believe, an esophoria of about 0.5Δ at the 20-foot distance and should therefore not be regarded as indicating orthophoria at infinity, but rather a small amount of esophoria.

In conclusion, from the results of our own and other investigations we believe that the best working conditions—as evidenced by the fact that about 70 per cent of emmetropic eyes and properly corrected eyes give such data—are those in which about three-fourths to four-fifths of the convergence necessary for binocular single vision is accommodative convergence, and that, as a result, in the great majority of cases an exophoria of approximately 1Δ at 20 feet is to be found at this distance of testing and is to be considered as indicative of genuine orthophoria at infinity. And, furthermore, these lines of reasoning which we have presented appear to indicate the folly of placing very much dependence upon the tonicity tests at the customary fixation distance which show either so-called orthophoria, a degree of exophoria or even a degree of esophoria in so far as any modifications in the refractive findings are concerned.

We find some examiners who reason that they should reduce the hyperopic corrections or increase the myopic corrections when any indications of exophoria at 20 feet are found. As a matter of fact it is a seven out of ten chance that an indication of 1Δ exophoria at 20 feet represents a genuine orthophoric condition.

A Study of Exophoria at the Reading Point

Morgan C. Davies, B. S., A. O.

A GREAT many cases of exophoria, particularly for a third meter, coming into the university clinics, led the writer to conduct some experiments upon this particular phase of exophoria. This condition (exophoria for near only) is unfortunately more or less ignored by most writers on heterophoria. It is perhaps possible that eyes suddenly forced into excessive close work would develop this condition. Experiment proves this and also gives several other probable causes. The purpose and procedure of these experiments is given in the following pages. It is unfortunate that a much larger number of cases could not be secured. However, it is felt that a sufficient number were secured to at least suggest the proper treatment applicable to each type.

All cases showing more than 2Δ at six meters were excluded. It is probably impossible to measure imbalance within 1Δ as selected cases tested over a given period varied, on an average, at least 1Δ from day to day. For this reason all cases presenting 2Δ or less lateral imbalance are considered orthophoric. While imbalances, if accurate apparatus is used, may be measured to one-fourth of a prism-dioptre, clinically small errors of fractions of a dioptre are negligible.

Practically all text-books recommend that exophoria at the reading distance be ignored or that an undercorrection of the error, if hypermetropic, be given. If hypometropic a full correction is urged. That these statements are only partially true will be evident from that which follows.

The testing of heterophoria at near (one-third meter) involves both accommodation and convergence, so that it is both a contraction and a tonicity test; hence the name, "Accommodation and Convergence Test." Unlike the test at six meters, the starting or zero point is the convergence

produced by the accommodative-convergence centers. The emmetropic orthophoric pair of eyes will accommodate three dioptres O. U. for thirty-three and a third centimeters and, for a pupillary width (really distance between centers of rotation) of six centimeters, will exert 18Δ of convergence as a total. If the pupillary width exceeds or is less than six centimeters more prism dioptries of convergence, or fewer prism dioptries of convergence will be needed. The innervation for this convergence is supplied by the associated center for accommodation and convergence. Thus it will be seen that while the starting point for this test is zero (*i.e.*, fusional centers not acting) it is a vastly different zero than the one upon which the six meter tests are based.

There are several tests that may be used, each of which depends upon "impossible fusion." The Maddox groove or rod or double prism, von Graefe's test, Stevenson's, etc., are all of about equal value. The writer uses a white test object with fine lines upon a black background. The white object on a black background is to prevent excessive reflection, the fine lines are to insure active accommodation, and the large size of the card, five by seven, serves to prevent the patient noticing anything likely to distract his attention. Some tests were also made with Sheard's test object.

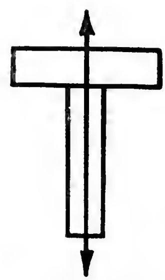

Fig. 1. Form of test object. This is made up and used by the writer in the form of a *white* test object with fine lines upon a *black* background.

Diplopia was produced by the use of a 6Δ prism, base down, over the right eye. This arrangement should not be criticized, since tests with prism equally divided, failed in over five hundred cases to show any noticeable difference in results. These tests were made during the years 1919-22. For the sake of brevity, only those cases showing exophoria at near are given. The 6Δ of "physiological exophoria" suggested by

Howe and substantiated by Sheard and others has been deducted from the results. For a total of eleven hundred and sixty-four cases, one hundred and forty come under the head of this paper. This shows a percentage of 12.02. The patients investigated include students, clerks, professional men and others; students, however, being largely in the majority, as the following table indicates.

TABLE I

Students	1009	Average	age	21
Instructors	42	"	"	31
Clerks	35	"	"	24
Laborers	12	"	"	34
Housewives	44	"	"	34
Unclassified	22	"	"	37

By eliminating all classes, except the students, the number of cases drops to one hundred and twelve for a percentage of occurrence of 9.6, or practically 10%. Thus it will be obvious that these cases are reasonably important, at least so far as college students are concerned. The small number of others available is too meager to allow of any very definite conclusions. For the students, the average amount of error present was 10Δ.

The diagnosis of "exophoria for near" is of course made from the accommodative-convergence test previously given, and with the six meter tests within the allowable limits, indicating orthophoria. However, before any conclusions as to the treatment and results of this imbalance may be drawn, a consideration of its influence upon several other functions or actions of the eyes is necessary; also the results to be obtained from other tests. The tests and functions they supposedly indicate are listed as follows:

Test	*Function*
Corneal image and screen test	Binocular vision
P. P. of convergence	Convergence
Version	Field of Fixation

P. P. of accommodation	Accommodation
Reserve fusional convergence	Fusion supplement
Refraction	Vision

Corneal Images and Screen Test

The corneal image test is made after the method of Maddox and in heterophoria is of course of no importance, since the images must be symmetrical, else heterophoria is not present. It is in the screen test made in conjunction with the image test that this condition manifests itself. The screen test at six meters is of course excluded, as orthophoria is presupposed. Placing a cardboard screen alternately over each eye while fixation is maintained shows a marked redress in of each eye upon being uncovered. A redress of one millimeter or less is due to the physiological exophoria present. Redress of more than one millimeter almost invariably indicated exophoria. This was of course expected since the accommodative-convergence test is also a binocular one. This test then gives us in the preliminary examination a good indication of the ocular poise for near points.

Punctum Proximum of Convergence

It has been stated that the near point of convergence must be at least three inches, indicating a convergence of at least thirteen meter-angles. However, one inch near-points indicating forty meter-angles are fairly common. A near point of more than three inches would be expected in exophoria but these experiments show that this is the case only once in a hundred patients. This proves that forced momentary convergence at least is possible. The secret of this test is in the endurance of the convergence; that is, it should be maintained for at least a minute. In these tests a white headed pin was used, the convergence fixation was maintained from ten to sixty seconds at the extreme near-point. The average may be given as thirty seconds.

Version Test

This is roughly a measure of the field of fixation. Excluding paresis and paralysis, these cases as well as all others show a normal field. The test object used was a small unhooded ophthalmoscopic light. The perimeter may be used as well as the tropometer of Stevens but where time is a factor, the little light does very nicely. Nothing about the exophoria apparently may be learned from this test.

Punctum Proximum of Accommodation

This test is very quickly made using the smallest type of the Jaeger test card. The card is approached toward the patient until he ceases to read: this is the binocular near-point. Alternately occlude each eye and determine the

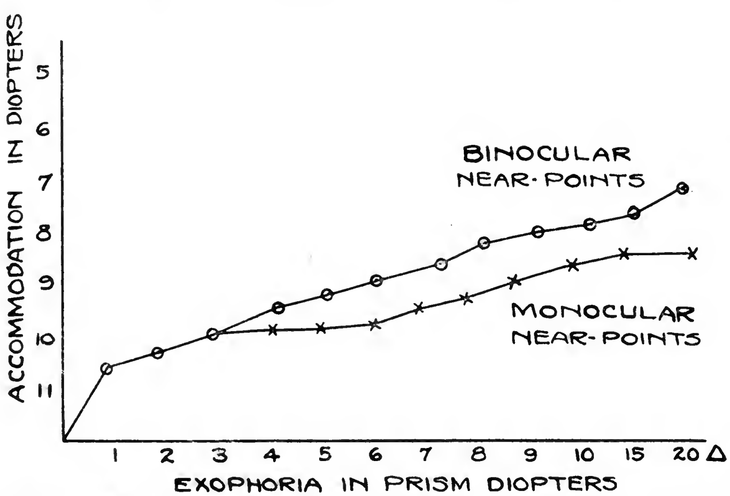

Fig. 2. Monocular and binocular near-points in conjunction with central convergence deficiency or "exophoria at the near."

monocular near-point. Without exception the uncorrected hypermetropic cases of this series had a receded binocular near-point, the monocular being in some cases a dioptre

better. In hypometropic cases little difference could be ascertained. The tests with corrections in place showed very little difference between monocular and binocular near-points. They did point, however, to a slightly more distant binocular near-point. This is not in keeping with theory; but is the practical result, nevertheless, which we have found. The results for uncorrected hypermetropia are graphically shown in Fig. 2.

The Reserve Fusional Convergence

After accommodation and convergence for a given point has been established, it is possible to cause either relaxation or exertion of convergence without altering accommodation. It is not practical to relax the convergence since we are unable to determine the point at which relaxation ceases and divergence (artificial amount to overcome prismatic power) begins. At any rate, it would have no important bearing upon the study of exophoria.

Fixation in exophoric cases is accomplished by the accommodative-convergence center, then the positive fusion center acts to overcome the "physiologic exophoria" plus whatever amount is necessary to overcome the real exophoria present. Since this exophoria is not manifest for six meters, it follows that it is purely innervational or functional and not anatomical. Also that it is very closely allied with accommodation, since the fusion centers do not act during accommodative-convergence tests.

Thus if, after fixation is established, we place increased prism strength, apices in, until diplopia occurs, the fusion reserve available to produce convergence has been measured. This is called the positive R. F. C. test. The negative test is of course just the opposite, but is of no particular interest in exophoric cases.

Before we may use the R. F. C. test to assist in treating this type of exophoria, some idea as to R. F. C. is necessary.

The results secured by C. E. Morris, B. S., and R. B. Gordon, B. S., are interesting in this connection. They found that the normal ratio of positive to negative R. F. C. was three to two; the positive varied from twenty to thirty-two prism dioptries with corresponding negative values. They also found that the strength varied directly with the condition of the subject; fatigue, illness, etc., resulting in reduced values

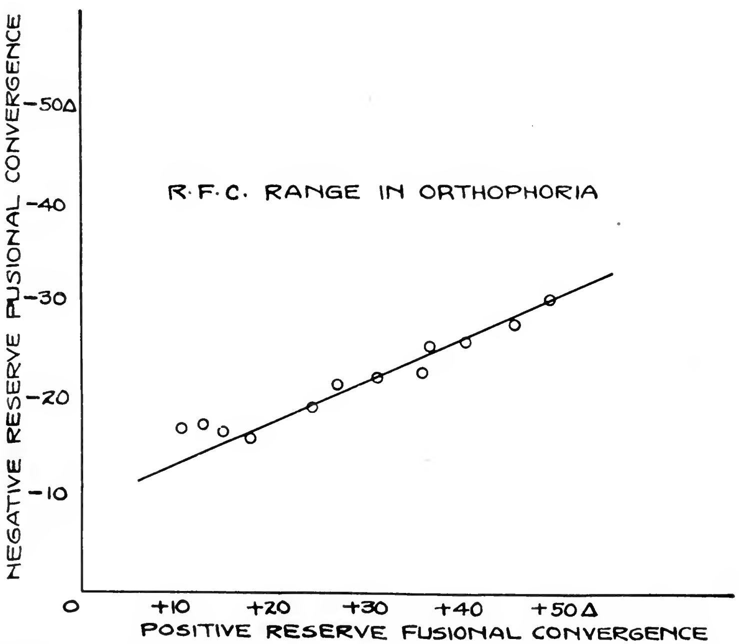

Fig. 3. Showing the ratio between positive and negative reserve fusional convergences at the normal reading distance, with orthophoria at distance.

without, however, destroying the normal ratio. Greater values were secured earlier in the day than later, and for obvious reasons. They also found that the amounts obtained were independent of the subject's age. That is, like amounts

were obtained from very young subjects as well as from very old ones. The graph shown in Fig. 3 was plotted from eighty-five orthophoric cases.

TABLE II

Total Positive R. F. C.	=	2294
Total Negative R. F. C.	=	1672
Number of cases	=	85
Average Positive R. F. C.	=	26.9
Average Negative R. F. C.	=	19.7

For the exophoric cases, the positive reserve fusional convergence declined and the negative apparently increased. This increase in the negative would indicate that all apparent orthophoric cases are really esophorias of low degree.

The average result of the exophoric cases is given in Table 3.

TABLE III

Total Positive R. F. C.	=	1860
Total Negative R. F. C.	=	2464
Number of cases	=	112
Average Positive R. F. C.	=	16.6
Average Negative R. F. C.	=	22

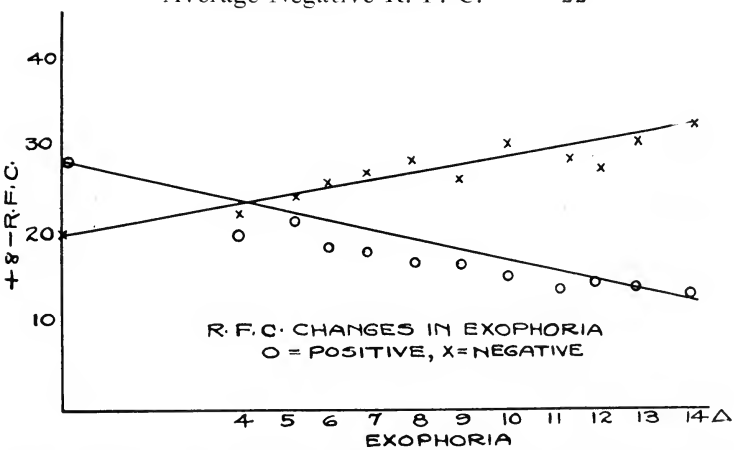

Fig. 4. Showing the decrease in positive reserve fusional convergence and the increase in negative reserve fusional convergence in exophoric conditions of the amounts given as abscissas.

Fig. 4 shows graphically the increase of negative and decrease of positive reserve.

Refraction Tests

It was found that these cases fell into three groups, as shown in the following table:

TABLE IV

Myopia	= 5	Percentage =	4.4
Hypermetropia less than +.50D	= 20	"	= 17.8
Hypermetropia more than +.50D	= 87	"	= 77.6
Number of cases	=112		

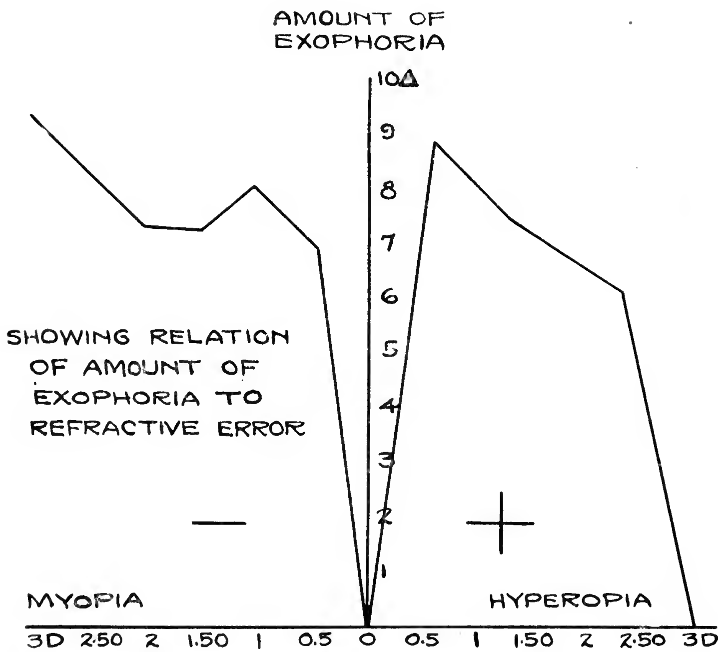

Fig. 5. Showing the relation of the amount of exophoria to the refractive error. The exophoria given is taken as the average amount for the respective error specified.

The myopic cases were fully corrected and experienced no difficulty. Their number, however, was too small to form any conclusions as to use of prisms, exercises, etc.

The hypermetropic cases below +.50D were all given a series of exercises. These cases were twenty in number. All were given their corrections with prisms from one to two and a half prism dioptries O. U. for reading. Five of the cases exhibited sufficient interest to report daily for exercises and we were able after three months to remove the prisms from three of them with no return of symptoms. The other two are now wearing the prisms with comfort for near work. Fifteen were given weak prisms with their corrections for near work only, with entire disappearance of symptoms. These symptoms have not returned to date and have been worn for an average of one and a half years. The correction of their refraction alone did not cause abatement of discomfort. These patients all suffered from binocular frontal and bulbar headaches. Their general health apparently was excellent. These results have been tabulated in part by K. G. Smith, B. S.

The patients with errors amounting to more than one-half dioptre were given their full binocular correction (six meters) for constant wear with disappearance of all symptoms. Seventy-five of the remaining eighty-seven came into this class. Of the remaining thirteen, three had renal disease, five were anaemic, one had bad tonsils and four had chronic constipation. Proper treatment, plus their corrections, relieved their symptoms, at least up to the date of this paper. As a matter of interest, thirty of the patients were examined by an osteopath and all had slight to medium dislocations of the several cervical vertebrae. As we were unable to arrange treatment for these patients, the effect of spinal manipulation is unknown, at least in these cases.

It is also interesting to note that all of these cases possessed the third degree of binocular vision. It might be added

that, excluding the cases of squint, all patients passing through the clinics possessed this type of binocular vision.

Conclusions

The following conclusions are possible by reason of the preceding experiments:

1 "Exophoria for Near" may be caused by
   a. Deficient innervation
   b. Uncorrected hypermetropia as well as hypometropia
   c. Systemic toxins

2 Relief for class (a) demands, in general, prismatic assistance, apices out.
   Relief for class (b) demands a full binocular correction with prism rarely necessary.
   Relief for class (c) demands treatment other than purely optical. (This is of course obvious.)

3 The wearing of prisms for this condition does not tend to weaken the medial recti or to strengthen the lateral recti.

4 The results of orthoptic exercises are much overrated and they are at least a "thankless task."

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A Dozen Worth-While Points in Ocular Refraction

Charles Sheard, M. A., Ph. D.

THE grandest mansion in the world is made up fundamentally of a heap of little things—masses of small stones, each one insignificant in and of itself, knit together with plaster and mortar but molded with a definite plan in mind and fashioned with skilled hands. The world's most famous masterpieces are but a maze of daubs of paint smeared on the canvas by the hand of the genius. And so on, *ad infinitum*—it is the old story of the worth-whileness of the little things in life. Just so with the most accurate and thoroughgoing examination of a pair of eyes; fundamentally it consists of a number of observations which may be considered rather elementary and simple but which, when put together by the thinking mind, go to make possible the ultimate analysis of the fundamental points of strength or weakness. Many men know how to get data of some kind or other, but few men know how to get *truthful* data and, in particular, fewer numbers of men know how to give heed to the *little things* which make so much for success. The main theme of this paper is, therefore, the worth-whileness of little things in ocular refraction—the justification of giving heed to details.

1. The Necessity of a System and Routine in Examination

Law and order are the great fundamentals upon which all successful enterprises and businesses are conducted. The business of making a thorough examination of a pair of eyes is no exception to this generalized statement. Without a routine set of tests and a definite order in which these tests are to be made many details of a thorough examination will be unconsciously omitted. By definite adherence to a rou-

tine, which becomes a matter of second-nature ultimately, there will be just as unconscious a getting and recording of data, so that no essential test will be omitted. These fundamental tests and the approximate order in which we make them are as follows:—

1 History of case.
2 Visual acuity tests without glasses.
3 Ophthalmoscopic and external eye examinations.
4 Ophthalmometric findings.
5 Static skiametric examination.
6 Dynamic skiametric examination.
7 Subjective tests; usually making the start with the spherical lenses obtained by the dynamic skiametric test.
8 Tonicity and duction tests with fixation at 20 or more feet.
9 Tests upon near-point, amplitude of accommodation or determination of the presbyopic findings.
10 Muscle tests at the customary reading or working distance.
11 Final lens changes and niceties of refractive findings or determination of final prescription in view of all the data.
12 Taking the patient into one's confidence, with clear, concise statements of what is to be expected, the character of the treatment, things to do and not to do.

Such a routine of examination, in essentials at least, has been adopted by many of our ablest refractionists. To be sure, such a detailed examination cannot be executed in a few minutes' time. But time, service and skill are what we should be offering those who come to us. And orderliness and a routine instill confidence in our clientelle.

2. Case History

Possibly no part of an examination is more important than getting and recording the essential points in the history

of a case. In the first place, it establishes a bond of sympathy between the examiner and the person examined and, in the second place, the asking of specific questions and the getting of specific answers furnish clues and leads to the ferreting out of the experiences and ocular history of the pair of eyes to be examined. As a patient once asked of an examiner: "Doctor, who knows whether I can see or not; you or I?" so who knows the symptoms of complaint and the previous life of the one being examined better than that person?

The questions asked should include inquiries into: (a) Occupation, conditions of work. (b) Age. (c) Condition of health, previous illnesses, accidents, etc. (d) Glasses previously worn; how long since prescription was changed. (e) Are your eyes disturbed in near vision? Distant vision? Do bright lights disturb? Do you get drowsy while doing close work? (f) Headaches and their location and frequency. (g) Questions relative to granular lids, conjunctivitis, epiphora, diplopia, photophobia, etc., expressed, of course, in lay language. (h) Questions relative to general systemic condition; condition of teeth, tonsils, and so forth.

All of these data and others like them should be recorded, since these facts, together with the results of various tests made, constitute the evidence upon which the practitioner must base his findings, and to which he may refer on subsequent examinations. They leave him the *master* and not the *servant* in his own sanctum.

While a routine ought to be followed in ocular refraction, still the alert and capable examiner always makes it a point to *study each case*. As we have often said and written: Each pair of eyes is a law unto itself; each pair of eyes is a part of a physical organization known as the human body; no facts known or data obtainable from either the eyes or the rest of the body are to be neglected. Every refractionist must, therefore, keep a happy balance between a set of tests more or less routine and essential and an openness of mind and

thought to quickly catch and appreciate vital points which may not fall within his routine.

Passing from these generalizations, the writer wishes to take up, in the order and manner in which they occur to him, some little worth-while tests in ocular refraction.

3. The Correct Use of Apparatus

Many practitioners get data but not all of them get correct data. This is often not due to ignorance of the essentials of different tests but due either to poorly arranged or poorly adjusted apparatus. We have known men to use an ophthalmometer—and either depend upon these findings or else discard the instrument as useless—when the eye-piece had not been properly adjusted or the mires did not register correctly. Or again, muscle tests are made with decentered lenses by reason of quite incorrect P. D. settings or with eyes set behind the phorometer or similar instruments in "hit or miss" or "as you please" fashion, or without leveling the instrument. Or retinoscopic findings are attempted with mirrors and lamps giving a letter S shaped reflection. Or, even worse, dirty, finger-printed trial case lenses are used in subjective testing. Every refractionist ought to know the correct use of and full value accruing from his instruments.

4. Twenty Feet Is Not Infinity

In testing presbyopes and in making up bifocal prescriptions, it is to be remembered that the 20-foot distance is optically equivalent to 1/6 diopter. Hence a slight undercorrection—about O. U. 0.25 D. S.—is to be recommended unless full or slight overcorrections are to be prescribed because of decided esophoric tendencies or in order to force out a spasm of accommodation.

5. The Binocular Addition of Convex Lens Power

A very simple but valuable test often omitted consists in

adding binocularly to the findings in the trial frames upon the patient's face, +0.25, +0.50 D. S., and so on, up to the point where the person being examined reports a noticeable loss in acuity. It is, as a general statement, true that binocular relaxation is greater than can be obtained monocularly. Therefore, if the findings in the trial frame afford 20/20 easily, and especially if the person under examination is under forty years of age, plus spheres should be added binocularly until some of the letters in the line last read are indistinct or unreadable. Under this procedure more convex and less concave lens power will generally be found to be accepted. The changes in lens power indicated may or may not be made in the light of the other data obtained, or by reason of the facts disclosed in getting the history of the case and symptoms of complaint.

6. Comparison of Acuity of the Eyes

One valuable test too often omitted is to determine whether or not the two eyes, each having monocularly been left with 20/20, or possibly 20/15 vision, or, at any rate, presumably equal acuity, actually possess a balanced acuity. In a case, for instance, showing O. D. +1.25 D. S., V=20/20 and O. S. =+1.00 D. S., V=20/20, it will often be found that the comparison of acuity of the two eyes will show one to be slightly better than the other. Let us suppose it to be the left eye in this case. We should then proceed to bring them, if possible, to equality by the addition of plus lenses before the better seeing eye until the patient expresses no preference.

A simple method of determining the equality of acuity consists in quickly shifting a small piece of cardboard or other cover from one eye to the other while the person under test is fixing the attention upon a given line of letters. Slight inequalities are often reported, and frequently these will be reported as being reversed if as low an additional

lens quantity as a quarter diopter plus sphere is held before the better seeing eye.

And again, when the monocular findings differ by a quarter or half diopter, a comparison of acuity with reduction to equality will often show that such a lenticular difference does not genuinely exist. Nothing indicating to the contrary, it is not proper to leave one eye with decidedly better acuity, provided the acuities can be made equal, for the reason that the better seeing eye will, in the main, carry on the function of distance vision, at least, and it should not be overtaxed.

7. The Dominant Eye and Its Significance

In every pair of eyes there is generally a dominant or "boss" eye. Quite frequently in right-handed individuals it is the right eye. The dominant eye may be readily found by having the person under examination look at the edge of an open door or other small vertical object and, with both eyes open, line up a finger of one hand, held vertically, with the object looked at. The examiner then determines whether the finger thus aligned is before the right or left eye, or perchance between the two. The last named condition, rarely found, indicates no dominant eye. Evidently, the function of the dominant eye is one of directing or finding, while the spatial location is determined through binocular sighting, the non-dominant eye being the one which actually does the moving or swinging into coördination with its mate. There are two points of practical significance with reference to the dominant eye in refractive work:—(1) If any preference is to be given, leave the acuity of the dominant eye slightly better than that of its mate, and (2) in the prescribing of prisms, especially in the correction of vertical imbalances, care should be exercised and the major portion, if not the total in some cases, should be placed before the non-dominant or non-directing eye.

8. Retinoscopic Examinations Along the Line of Vision

One simple procedure in static skiametric examinations which is almost universally violated is the obtainance of the findings along the line of vision. When cycloplegics are not used, it is customary for the examiner to make his retinoscopic findings at an angle.

This method of operation introduces the actual presence or at least liability of the presence of errors due to the following causes:—(1) The posterior half of the eyeball, in so far as the contour of the retina is concerned, is not necessarily a spherical surface, and since one millimeter difference in depth represents three diopters of refractive change, the determination of the refractive error by reflexes coming from other portions of the retina other than the macula, or as close to it as possible, is likely to be in error. (2) It is a well-known fact in optics that a spherical lens of relatively high power—and the eye is equivalent to a lens of high dioptric value—when tilted has the same effect as a sphero-cylindrical combination, in which the spherical portion is different from the true value of the sphere, together with the introduction of a cylindric element which did not exist previously. By reason of this procedure at an angle in retinoscopic examinations a true error which should be corrected by—0.25 cyl. ax. 90°, for example, may be found retinoscopically to be of the order of +0.25 cyl. ax. 90°, or scissor movements may be present. Greater exactness and greater value to retinoscopic findings will accrue if the findings are made along the visual line as closely as possible. Such can be done with a simple device consisting of two plane mirrors set parallel to each other and arranged at the proper position before the subject's eyes. This device is commonly spoken of as the macular reflectoscope.

9. Some Points in Correcting Astigmatism

In the first place, the writer has long since discarded the use of plus cylinders in subjective tests. Irrespective of

other methods or tests the writer believes that fogging tests, conducted reasonably rapidly with the information furnished by the retinoscopic tests, and the use of *minus* cylinders, are superior to the methods involving *plus* cylinders.

In making astigmatic tests care should be exercised to see to it that these tests are not conducted when the retina occupies the intermediate position in the interval of Sturm known as the circle of least confusion. A good procedure is to allow the eye under test, as the fog is reduced and a portion of a line of letters read, to view the astigmatic dial and to inquire relative to the ability to differentiate inequalities in these lines.

The writer has also discarded the common form of fan-chart with the sets of three lines lying at 0, 30, 60, 90, 120, 150 and 180 degrees respectively. He much prefers a chart with single radiating lines, each line being 10 degrees from the next one. An auxiliary test or check which is most serviceable consists of an arm, fastened at the center of the radiating line chart, which carries a small disc lying in the plane of the chart. This disc carries on its face a large V, made of two equally black limbs. One of the principal axes of astigmatism is located where the two limbs of the V are equally distinct (or indistinct if one desires to put it that way). By means of the arm carrying the V, this V may be set over any line on the radiating-line chart. When the two limbs of the V are equally distinct, the line at which the tip of the V points will represent the meridian of astigmatism to be corrected. This test is quite sensitive.

Another simple test as to the adequacy of amount and axis of the selected cylindrical correction consists in slowly fogging out the lines of the multiple, single-lined astigmatic chart. If properly executed, the lines will all fade out equally.

Another point needing emphasis is that of the great desirability of uniform illumination over the surface of the astigmatic chart. The writer has seen charts so illuminated as to

give the white background a white appearance on one side and a reddish appearance on the other. Such is to be avoided.

In fact, we cannot urge too strongly that all charts and dials used in subjective testing be uniformly and adequately illuminated. The day of the use of a two- or three-foot card of Snellen letters with the appended astigmatic fan-test illuminated with a single low-wattage carbon lamp enclosed in a reflector and put at the top of the chart, has gone by and yet hundreds of practitioners are still sticking to it.

10. A Simple Test for the Near-Point

Various tests, both objective and subjective, may be employed for determining the near-point and the amplitude of accommodation, either monocularly or binocularly. When the ordinary Jaeger types are used, as commonly found on our near-reading cards, two questions often arise: (1) What size type is to be used in the test? (2) If the acuity cannot be raised to standard by the distant findings, then how can one get the correct near-point subjectively? The writer's answer is that neither question can be answered with any accuracy for various reasons which space precludes our endeavoring to outline. But a very simple answer can be given in the form of a practical solution or substitute for these tests, namely: to place the determination of the near-point upon the basis of the first indication of the loss of or a change in the *detail* of the object looked at, irrespective of how sharp this detail may be. Taking one of the ordinary near-reading cards and holding this at a foot or more from the face, the smallest type which the subject can distinctly see (*i. e.*, with detail) is chosen.

In cases of presbyopia, some additional lens power must be given to assist in the test. Taking this type, therefore, as the basis of test, a monocular near-point may be obtained by slowly drawing the card toward the eye—its mate being

occluded—until the smallest discernible change or loss of detail is found. The distance from the anterior focal point of the eye—approximately 13 mms.—to the position found, will determine the near-point and from that the apparent or available amplitude will be disclosed.

The test as outlined above depends upon the following fact: When the object is focused as accurately as possible upon the retina the detail will be the best obtainable. As the object is approached toward the eye, if the detail remains as good as before the object was shifted, there is fair proof that accommodation has been called into play to the amount requisite to keep the image focused on the retina.

11. Testing Equality and Range of Accommodative Amplitude of Each Eye

The near-point of each eye and from it the apparent amplitude of accommodation monocularly should be obtained, and variations from equality should be the subject of further tests and observations. Inequalities of near-point values or apparent amplitudes of accommodation should, in the first place, cast a shadow of doubt upon the accuracy of the subjective findings made at distance.

To illustrate: Let us assume findings showing O. D. +1.50 D. S. and O. S. +2.00 D. S. with acuity in each eye 20/20 and reported equally good. If the near-point for the right eye should be found to be 25 cms. (or an apparent amplitude of 4D) and of the left eye at 22 cms. (or an apparent amplitude of 4.55D) we should immediately suspect that the right eye had been undercorrected and should proceed to endeavor to induce a greater relaxation and bring the amplitudes to equality.

In cases where this cannot be done through a satisfactory change in the distance corrections, and where a separate pair of reading glasses or bifocals are called for or indicated, we then believe that, from the optical standpoint, such

reading corrections should be given as will equalize the near-points and amplitudes.

Inequalities of any considerable amount—as a diopter or more—in the accommodative amplitudes in pairs of eyes in which approximately equal acuity conditions under the prescribed distance corrections exist, should put the examiner in an inquisitive frame of mind and lead him to make tests or have others make tests to find out whether any focal points of infection or other pathologic conditions, possibly in incipient stages, are existent. In passing we make the remark that amplitudes of accommodation, both as to their amounts and their equalities—and binocularly as well as monocularly from another angle possibly—are of vital importance to the refractionist.

12. The Importance of Vertical Imbalance

We have said nothing in this article thus far about the familiar and, as we feel, very important subject of the examinations as to the liabilities and resources of the extrinsic muscles. As to exophoria and esophoria, where either of these exists, with errors of hyperopia or myopia, as to reductions or increments in correcting lens power, the giving or the withholding of prisms and of prismatic and other exercises, different opinions exist, and one can find authority of some kind or other for almost any procedure.

But nearly all practitioners who have gone into the muscle problem have agreed upon the importance of the testing of and the offering of prismatic assistance in cases of genuine vertical imbalance. This apparent agreement arises from the facts that: (a) Vertical imbalances and accommodative excesses or deficiencies are very rarely interrelated, (b) vertical imbalances are often the primal cause for conditions of lateral imbalance and (c) small vertical imbalances are of real significance because of the fact that the superducting and infraducting powers are of low amounts,

generally of the order of 3Δ each. In cases of a degree or so of hyperphoria, which may be present and uncorrected, binocular single vision generally is obtained with discomfort and the two eyes when endeavoring to work together have a less keen and sharp visual acuity, both at distance and while engaged in close work such as reading, than when each eye separately is used. Whenever the binocular visual acuity, in eyes which possess equal visual acuity, is not better than the monocular acuity or in cases in which the binocular amplitude of accommodation is not in excess of the monocular finding, the writer believes that there is generally indicated by such data the presence of an interfering extrinsic muscular imbalance, usually a *vertical* imbalance. The writer has for some time, as a routine test, discarded the Maddox rod used in conjunction with a small spot of light for the determination of muscular imbalances. He much prefers the Maddox double prism, or the use of a Risley rotary prism with sufficient prismatic power, turned base in or base up before one eye, to throw the image formed upon the retina of the non-fixating eye well outside of the fusion areas. These tests should be made at both distant and reading points.

As to the amount of prismatic assistance to be given in cases of vertical imbalance, the writer believes it to be good practice and a first approximation to the truth, at least, to add such an amount of prism, base up or down, as will equalize the supra- and infraduction. Inequalities of ductions, which are practically reversed when the ductions of the other eye are taken, are nearly always indicative of a vertical imbalance. In one of our modern testing instruments we find a Risley prism with about a 15Δ range which enables us to accurately get both the measure of the vertical imbalances and the values of the vertical ductions.

As a closing remark, we wish to state that many a pair of glasses has been unsatisfactory to the person to whom they have been given by reason of the fact that the line

joining the centers of the lenses did not lie on a line parallel to the line joining the outer canthi of the eyes, or in other words there was an effect of prism, base up or down as the case might be, when no vertical imbalance of any measurable amount existed in the eyes tested.

Yes, indeed! The grandeur of the science of ocular refraction is made up of a multiplicity of little things.

Division of Ocular and Professional Interests,
American Optical Company,
Southbridge, Mass.

Binocular Vision and the Field of View

A. Whitwell, M. A.

WHEN a small near object is examined critically by the two naked eyes the optic axes *om*, Fig. I, of the eyes converge and intersect in a point on the object. A small pencil of light from the object enters the pupil of

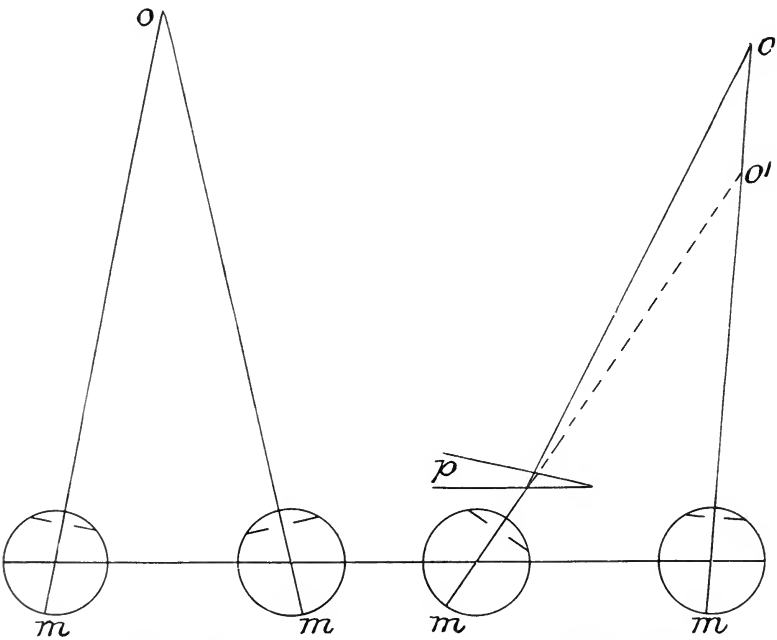


Fig. I. Fig. II.

each eye and is brought to a focus on the macula *m* as shown in Fig. I. When a lens, prism, or binocular instrument is placed in front of the eyes the pencils of light from the object in general suffer deviation by the lenses, prisms, etc., of the instrument and the object appears to be displaced.

For example, if a prism p base outwards, as shown in Fig. II, be placed between the object o and the left eye, the object will appear to be at o' instead of at o.

In the following article I propose to investigate the apparent change in the field of view when a pair of spectacle lenses of various different forms and set at different distances apart are used.

Method Used

The method to be used is to trace a pair of rays from a point on the object through the two lenses and to find the intersection of the two emergent rays, or the two directions in which the two eyes see the object, always supposing that each emergent ray passes through the center of rotation of the corresponding eye. The simplest and most obvious procedure would be to take points in a vertical object plane at right angles to the optic axes of the lenses and at a given distance from the eyes and to find the locus of the corresponding image points or the locus of the intersections of pairs of emergent rays. The difficulty in this procedure is that of finding the points of incidence on the lenses and the angles of inclination of the incident rays such that after refraction by the lenses the emergent rays will pass through the centres of rotation of the eyes. To get over this difficulty I suppose the *image* to be a plane, and I draw through each point in this plane two rays which pass through the centers of rotation of the eyes and trace these rays backwards through the lenses and find the corresponding incident rays. The intersection of each pair of such rays will give me a point on an object surface which when examined through the lenses will appear to be a plane. In reality, therefore, what is done is to find the principal curvatures of an object surface which will appear plane instead of assuming a plane object and finding the principal curvatures of the corresponding image surface.

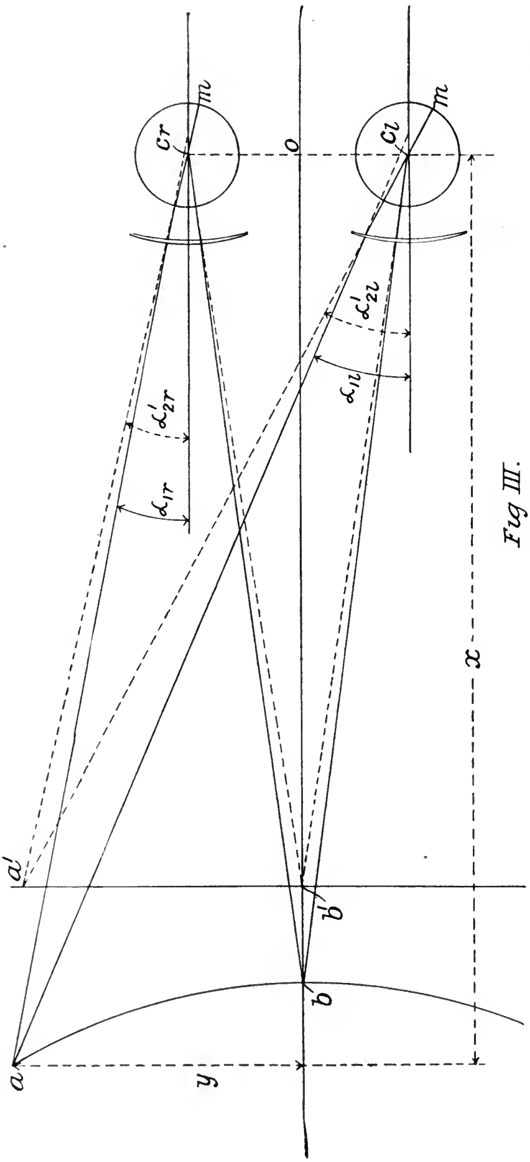


Fig III.

Assuming the eyes to be looking horizontally straight forwards, Fig. III represents a horizontal section through the centres of rotation c_r, c_l of the eyes and the centres of the lenses. The subscript letters r and l will always refer to the right and left eyes. The section of the object surface is marked a, b, and that of the image plane a', b'.

Notation

In every case the power of the lenses was taken as 4D+.

$\mu = 1.53$ = index of refraction of the glass.

$d = 25$ mm. = .025 m. = distance of the centre of rotation of the eye from the last vertex of the lens.

$t = .003$ m. = axial thickness of the lenses.

Interpupillary distance = 60 mm.

Distance $b'o$ of the image plane from the line joining the centres of rotation of the eyes = 40 centimeters.

o is the origin of co-ordinates.

$o\ c_r\ c_l$ = axis of y; $ob'b$ = axis of x.

$o\ c_r = o\ c_l = 30$ mm. = .03 m.

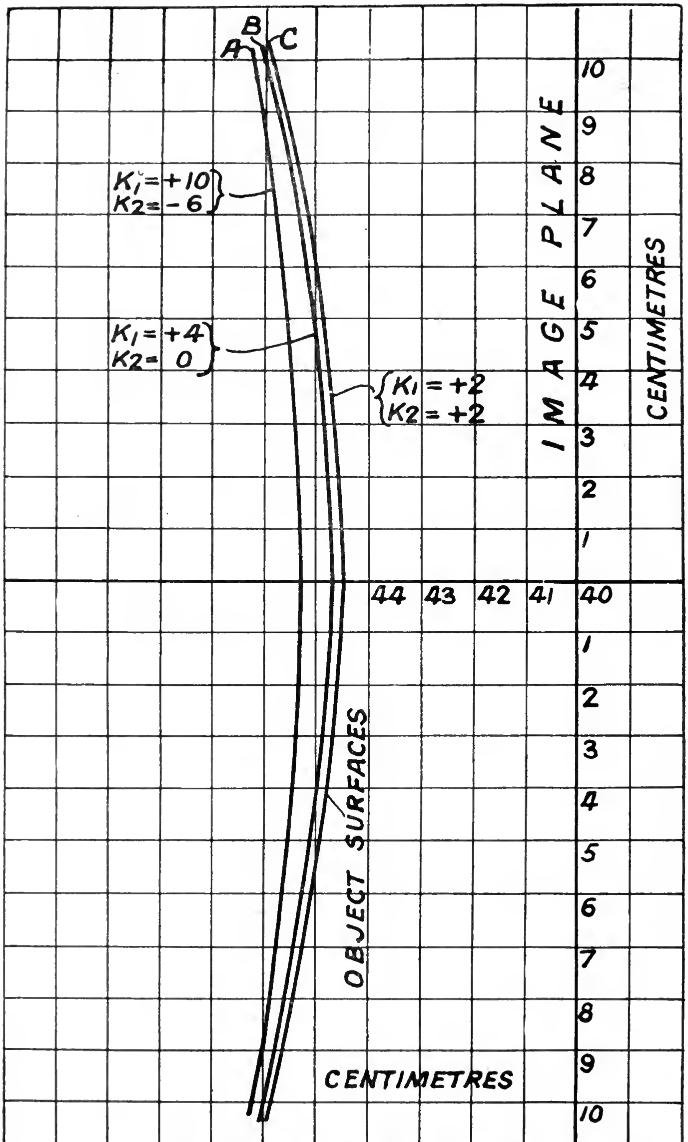
a_{1r} or a_{1l} = angle between a ray incident on the first surface of a lens and the optic axis of the lens.

$a_2{}'_r$ or $a_2{}'_l$ = angle between the corresponding emergent ray and the axis of the lens.

x_{1r} or x_{1l} the distance between the first vertex and the point in which a ray incident on the first surface cuts the axis of the lens.

$x_2{}'_r$ or $x_2{}'_l$ = 25 mm. = distance between the last vertex and the point where an emergent ray cuts the axis of the lens.

In Fig. III rays $a'c_r$ and $a'c_l$ are drawn from a point a' in the image plane through the centres of rotation of the eyes. These rays are traced backwards from right to left and intersect at a which is the object point corresponding to the image point a'. Given the point a' and the angle $a_2{}'_r$ the value of a_{1r}, a_{1l}, x_{1r}, x_{1l} were found by trigonometrical computation in the usual way, four figure logarithms being used.



A
B
C
K1 = +10
K2 = -6
K1 = +4
K2 = 0
K1 = +2
K2 = +2
IMAGE PLANE
CENTIMETRES
OBJECT SURFACES
CENTIMETRES
10
9
8
7
6
5
4
3
2
1
40
1
2
3
4
5
6
7
8
9
10
44 43 42 41
47 46 45 44 43 42 41 40

Fig. IV.

The equations to the rays incident on the right and left lenses respectively are

$$y = -x \tan a_{1r} + (x_1 - t - d)_r \tan a_{1r} + .03 \text{..........} (1)$$

$$y = -x \tan a_{1l} + (x_1 - t - d)_l \tan a_{1l} + .03 \text{....} (2)$$

Where $x_1 - t - d$ = distance between the centre of rotation of the eye and the point where an incident ray cuts the axis.

Solving the equations (1) and (2), and substituting the values of x_{1r}, x_{1l}, a_{1r}, a_{1l}, found by computation we get the co-ordinates of the point a.

Horizontal Curvature of Object Surface

Fig. IV shows the values of x and y plotted for three forms of lens. Curve A corresponds to a meniscus lens having the power of the first surface $\kappa_1 = \frac{\mu - 1}{r_1} = +10\text{D}$ and the power of the second surface $\kappa_2 = -\frac{\mu - 1}{r_2} = -6\text{D}$; curve B to a convexo-plane lens having $\kappa_1 = +4\text{D}$ and $\kappa_2 = 0$; curve C to a double convex lens of $\kappa_1 = \kappa_2 = +2\text{D}$.

The curvature of the object surface at the point where it cuts the axis of x was found from the relation

$$\frac{y^2}{2r} = x_a - x_b$$

Where r is the radius of curvature y and x_a the co-ordinates of a point on the object surface for which the angle $a_2'{}_r$ of the emergent ray is 10° and x_b the value of x corresponding to $y = 0$. The variation of the horizontal curvature of the object surface when the lens is "bent" is shown by the curve H in Fig. V, in which the abscissae are the powers of the second surface in diopters and the ordinates, the curvature in diopters. By "bending" the lens I mean, of course, that the powers of the two surfaces are varied whilst the power of the whole lens is kept constant. It will be seen

that the lens has been bent from the form of a meniscus having a second surface of 6D+ to one having a second surface of 6D—.

The curve shows that the curvature of the object surface which will appear plane to the eyes is greatest when the power of the second surface of the lens has its greatest positive value and least when the second surface has its greatest negative value. The field will appear flattest when the meniscus has its concave surface towards the eye.

It is legitimate to deduce that if the object surface be flattened, that is, if the point a (Fig. III) move to the right the corresponding image point a' will also move to the right so that when the object surface becomes plane the image surface will become concave. Whatever therefore be the form of the lens, a plane object will appear to the eyes to be concave.

Vertical Curvature of Object Surface

Up to now we have only dealt with the curvature of the object surface in a horizontal plane containing the optic axes of the lenses. We will now consider the curvature in the median plane, that is, a symmetrical vertical plane at right angles to the paper in Fig. III and containing the axis of x.

Suppose the emergent ray $a'c_r$, Fig. III, and the corresponding incident ray to rotate about the axis of the right eye lens until the point a' comes into the median plane as shown in elevation and side view in Fig. VI, and also suppose another ray $a'c_1$, equally inclined to the axis of the left lens, and its corresponding incident ray to rotate on the axis of the left lens till the point a' comes into the median plane. Everything being symmetrical the two points a' will coincide and if a line $a\ a'$ (Fig. VI) be drawn parallel to the axis it will be seen readily that the two incident rays will intersect in the point a (Fig. VI), in the median plane. Two rays coming from an object point a in the median plane will after

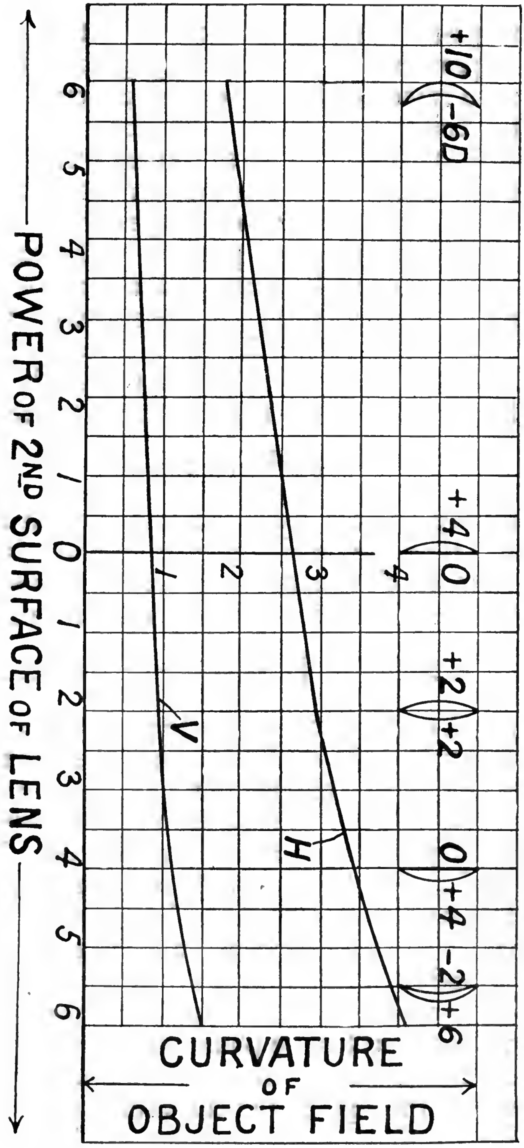

POWER OF 2ND SURFACE OF LENS
CURVATURE OF OBJECT FIELD
+10 -6D
+4 0
+2 +2
0 +4
-2 +6
V
H
0 1 2 3 4
6 5 4 3 2 1 0 1 2 3 4 5 6

Fig. V.

refraction pass through the centres of rotation of the eyes and will appear to come from an image point a' in the median plane at the same height above the horizontal as the point a. As the point a' moves up and down the straight line a' b' (Fig. VI), the point a will trace out the curve a b, which is the section by the median plane of the object surface which will appear to the eyes as an image plane. To find the x and y of any point a in the curve a b, suppose a_2' to be the angle between the axis of one of the lenses and an emergent ray $a'c$, the subscript letters being dropped since the quantities refer to both lenses. The projection of the line $a'c$ on the image plane is $= .4 \tan a_2'$. The y of the point a is obtained from the relation

$$y^2 + (.03)^2 = (.4 \tan a_2')^2$$

as will readily be seen from the side view in Fig. VI, remembering that the semi-pupillary distance is .03 meters and the distance of the image plane from the eyes is .4 meters.

The x of the point a is obtained from the relation

$$.4 \tan a_2' = \{ x + (x_1 - t - d) \} \tan a_1$$

where x_1, t, d, have the same meanings and values as before.

The curvature in the median plane at the point b (Fig. VI) is obtained in a similar manner to that in which the horizontal curvature was found. The variation of the vertical curvature of the object surface as the lens was bent is shown by curve V in Fig. V. The vertical curvature varies similarly to, but it is always less than, that of the horizontal curvature.

The object surface which will appear to the eyes to be plane is therefore convex towards the eyes but appears to be flatter in the vertical than in the horizontal meridian. If we assume the object to be plane the image will be concave but flatter in the vertical than in the horizontal meridian. If we suppose the sign of the curvature to follow the same convention as that of the surfaces of the lens then the

curvature of the object surface which appears to the eyes plane will be negative and the curves H and V (Fig. V) should be reversed about the axis of x. I did not think of this when I drew Fig. V.

Distance Between Object and Image Surfaces

The distance along the axis of x between the object and image surfaces continually diminishes as the lens is bent from the meniscus form have $\kappa_2 = -6$D. to the meniscus form having $\kappa_2 = +6$D., in the first case it is 53 mm., see Fig. IV, and in the second 41 mm.

The following Table I gives the values of the various quantities found by trigonometrical computation.

TABLE I.

Horizontal and Vertical Sections of Object Field

$K = 4D+$; $a_2'r = 10°.0'.0''$; $a_2'1 = 18°.4'.15''$

k_1	k_2	a_{1r}	a_{1l}	x_{1r}	x_{1l}
+10	—6	8°.45'.44"	15°.47'.17"	.0312	.0314
+ 7	—3	8°.49'.56"	15°.53'.7"	.0308	.0310
+ 4	0	8°.53'.39"	15°.56'.56"	.0304	.0308
+ 3	+1	8°.54'.24"	15°.56'.59"	.0304	.0307
+ 2	+2	8°.55'.38"	15°.59'.1"	.0302	.0306
+ 1	+3	8°.56'.48"	15°.59'.26"	.0300	.0306
0	+4	8°.57'.20"	16°.0'.10"	.0300	.0305
— 2	+6	8°.59'.7"	16°.0'38"	.0297	.0303

$a_2'_r = 10°.0'.0''$		$a_2' = \pm 4°.17'.19''$, $y = o$	Curvature in Diopters	
x	y	x	H	V
—.4625	.1018	—.4532	—1.79	— .60
—.4610	.1021	—.4497	—2.17	— .70
—.4606	.1025	—.4465	—2.68	— .80
—.4604	.1025	—.4457	—2.80	— .90
—.4605	.1027	—.4450	—2.94	— .95
—.4614	.1030	—.4439	—3.38	—1.03
—.4614	.1030	—.4432	—3.43	—1.13
—.4628	.1035	—.4413	—4.08	—1.52

The Effect of Decentering the Lenses

In order to find whether the horizontal curvature of the object field which appears to the eye to be plane is affected

by decentering the lenses I took as an example a convexo-plane +3 D. lens, the particulars being as follows:—

$$\text{Power of 1st surface} = \kappa_1 = \frac{\mu - 1}{r_1} = 3\text{D} +$$

$$\text{" \quad 2nd \quad "} = \kappa_2 = 0.$$

$$\text{Total Power K} = \kappa_1 + \kappa_2 - \frac{t}{\mu}\kappa_1\,\kappa_2 = 3\text{D} +$$

Index of refraction $= \mu = 1.5$
Axial thickness 1.5 mm.
Diameter of lenses 36 mm.
Interpupillary distance 60 mm.
Distance of centre of rotation from last vertex $= 25$ mm.

The image plane was taken as the front focal plane of the lenses so that it was distant from the centre of rotation by an amount

$$= 1/3 \text{ m} + 1.5 \text{ mm} + 25 \text{ mm}.$$
$$= .3598 \text{ meters}.$$

I employed the same method as before and computed for two points for each amount of decentration. One point was that in which the median line cuts the image plane and the other was that in which the image plane is cut by a line passing through the centre of rotation of the right eye and making an angle of 8 degrees with the axis. I then used the formula $\frac{y^2}{2R} = x_{8^\circ} - x_0$ where R is the radius of curvature.

Table II (which is to be found on page 469) gives the results of the computations.

The results are plotted in Fig. VII. The decentration is measured along the axis of x, inwards to right, outwards to the left, each division representing 1 mm. The curvature is measured along the axis of y positive upwards, negative downwards, each division representing .2 of a diopter. The curve turns out to be almost exactly a straight line, that is to

say, the curvature is directly proportional to the decentration.

Expressed in a simple formula:

Curvature in diopters = .2677 × decentration in millimeters — 2.192.

When the decentration is a little over 8 mm. inwards the curvature = 0, that is to say, the field is practically flat.

It may be well to explain clearly the meaning of the curve in Fig. VII. The ordinates represent the curvature of the object field which will appear to the eyes to be plane. I suppose light to travel from left to right and a surface is supposed to have its curvature positive when it is convex to the incident light. Hence, when the decentration is between 8.2 and 10 mm. inwards the object surface which will appear plane is convex towards incident light and concave towards the eye so that if the object were plane the image would appear convex. On the other hand if the decentration is less than 8.2 millimeters inwards, or if it were outwards, then the object surface which appears plane will be concave to the incident

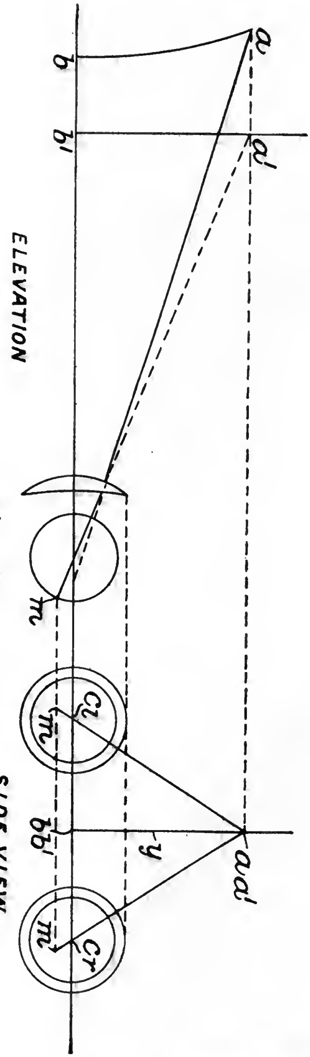
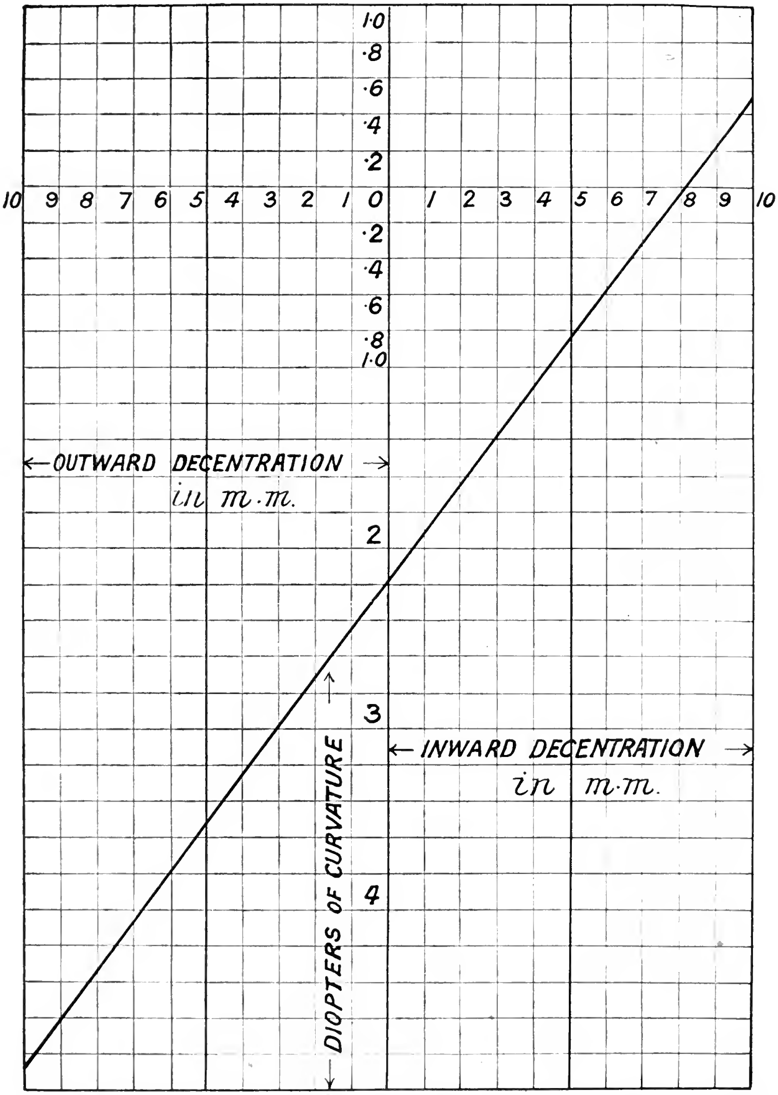


Fig. VI.



RELATION BETWEEN DECENTRATION AND CURVATURE OF FIELD

Fig. VII

light and convex to the eyes, consequently if the object is a plane it will appear to be concave.

TABLE II

	Decentration in mm	*Curvature of Field in diopters*
Inwards	10	+ .4848
	9.5	+ .3553
	9	+ .2202
	8.5	+ .0932
	8	— .0456
	6	— .5732
	3	—1.359
	0	—2.192
Outwards	3	—2.982
	5	—3.528
	10	—4.859

Conclusions

Remembering that we have only considered a few particular cases we have found:

1 Whatever the form of the lenses, so long as they are properly centered, an object-surface which will appear to the eyes to be plane must be convex towards the eyes. In other words, a plane object will appear to be dished or concave.

2 The horizontal curvature of the object-surface which appears to be plane will always be greater than the vertical curvature.

3 Both the horizontal and vertical curvatures of this object surface will be least when the

lens is of the meniscus form with the concave surface towards the eye and greater when the meniscus has its convex surface towards the eye.

4 There will be the least displacement of the image or the object and image will most nearly coincide when properly centered lenses are of the meniscus form having their *convex* surfaces toward the eyes; and conversely the displacement of the image will be greatest when the *concave* faces of the meniscus lenses are towards the eyes.

5 The effect of inward decentration is to diminish and that of outward decentration is to increase the curvature of the object-surface which will appear to the eyes to be plane. In other words, inward decentration makes a plane object look less concave or flatter and outward decentration makes it look more concave.

6 There is a critical amount of inward decentration which will make a plane object appear to be plane; beyond this amount a plane object will appear to be convex.

7 When the lenses are decentered outwards the image is nearer to the eyes than the object; when they are decentered inwards the reverse is true except for very near objects.

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Abstracts and Reviews

Perspective—Its Relation to Perfect Vision

George A. Shepard, M. D.

THE writer asks the question: What is perfect vision? In answer he says:—

1 Ability to see the seventh line on the Jaegar test chart at 20 feet, while the accommodation is at rest.

2 Ability to hold these two ocular images, as recorded upon their respective cortical centers, superimposed one upon the other, without muscular stress.

3 Dressing this composite image in its psychic garb, called perspective.

4 Recording the distance of the object as found by our range-finder; this instrument of triangulation being formed by the pupillary distance and the two base-angles made by the visual lines which point at the object. If the above results are *not* attained the vision is defective. If they can *only* be attained through the expenditure of undue effort, nerve-exhaustion ensues. It is commonly accepted that great benefit is derived from the wearing of glasses which correct refractive faults. Many at this time practice the correction of muscular imbalance by operation, wearing of correcting prisms, and prism exercise. But how many feel that it is at least as necessary to guide children toward accuracy of binocular single vision as accuracy in figures? The child who finds it impossible to fuse automatically the two ocular images has difficulty in concentrating the mind upon the work at hand because so much nerve force is wasted in trying to control these images. If all children in the sixth grade were examined with stereoscopic pictures, and when found below normal given some training, much trouble in later life would be avoided.

An infant has vision with both eyes, but the two images are recorded as separate units and the child sees double. The ball on the tray is seen double, and when the hand grasps it and it is held up in front of the child's face to be gazed at, cross-eyed, the child looks back to see the other ball, only to find none. Finally experience teaches that when two balls are seen there is really only one ball. Thus dawns the state of binocular single vision upon which is based triangulation and perspective. Until this is fully established, at about the sixth year, the child is clumsy and unable to bear long continued concentration. In the early days of kindergarten instruction, in this country, children of four years of age were asked to stick pins into holes to form simple designs. Owing to undeveloped perspective sense this employment proved too great a tax upon the nervous system of many children, and the methods of Froebel fell under a cloud from which it took many years to emerge. The multitudinous activities of childhood stimulate the functional growth until more or less perfect coordination takes place and it passes under the control of the subconscious sphere, just as takes place in learning to walk.

The chief direct causes of defective development of perspective are: (1) Over-convergence (esophoria or cross-eye); (2) divergence of the eyeballs or lack of convergence at the near point (exophoria), and (3) vertical deviation, or hyperphoria. Contributing causes are physical weakness and temperamental laziness. Cross-eye may be due to congenital shortening of the internal recti or, as is usually the case, to hypermetropia or far-sight; which, if uncorrected, calls for an abnormal effort of accommodation—which in its turn compels the convergence to overactivity. As the two visual images fall on their corresponding cortical areas *only* when the visual lines point to the object, double vision results. In order to avoid double vision one of the images is suppressed more or less completely and the effort to es-

tablish a range-finder is abandoned. This happy (or unhappy) result is accomplished the *more* easily if the vision of one eye is poorer than that of the other, or if the child's strength is not great or if there is temperamental laziness. Although a one-eyed person can make an estimate of a distance or perspective by a study of shadows, if sufficient time is allowed for the act, it can never be so consistently accurate as when binocular single vision exists, and it is much more costly in nerve force. Necessarily, the activities of the child are restricted to those which do not call for instantaneous estimate of distance and perspective. The boy who plays ball is dubbed a muffer or a poor batter; he fails to excel in those games which require perspective judgment; he cannot drive a nail straight or enjoy that game which in my boyhood was called "following the leader." When he climbs over a house, under construction, he is in greater danger of accident through miscalculation of distance, hence he is afraid to venture. A girl finds great difficulty in sewing or doing certain kinds of fancy-work, playing tennis, studying birds, looking through opera glasses, etc. Thus following the line of least resistance certain activities are eliminated because of their great nerve-cost or because of mediocrity of accomplishment.

The writer then asks the question: If we find a muscular fault which makes fusion of the two visual images difficult, with a low fusion ideal or an impaired sense of perspective, shall we leave well enough alone or try to enlarge the patient's appreciation of the visual world? After citing several illustrative cases he says:—Treatment consists in correction of the muscular and refractive faults which have been the cause of the defective condition, and stimulation of the fusion and perspective ideals by stereoscopic exercises and word pictures. As all advancement is founded upon an acknowledgment of previous error, the patient must be sufficiently intelligent to accept argument with an open mind and, therefore, cases must be selected with judgment or

results will be disappointing. Children only need to have removed the material obstacles to the attainment of perspective, while adults have, in addition, the faulty habits of thought and action which are formed by the presence of this defect. Therefore, simple methods of exercise with the stereoscope and prisms, at home or in school, will be all that is required for children. Adults must be studied individually so as to discover the primary cause, and then given exercises which will create a fusion ideal upon which can be built a perspective image. The method by which this is accomplished must vary according to the case, and, of course, cannot be presented in a paper of this sort.

(Abstracted from *Journal of Ophthalmology, Otology* and *Laryngology*. Vol. XXV, p. 121, 1921.)

Vertigo

G. W. Mackenzie, M. D.

THE major portion of this article deals with aural vertigo. After offering as a definition of vertigo the statement that it is a feeling of confusion which results from contradictory perceptions of position or motion in space, he goes on to write with reference to ocular vertigo the following:—

The eye, by reason of certain pathologic changes, tends to falsify our perceptions coming from that important organ of orientation far oftener than one would be inclined to believe, judging by the slight attention paid to the subject of vertigo by the average text-book author. Ocular vertigo is more common, and hence better understood than the kinesthetic form; while vertigo of aural origin is most common and the best understood of all.

Let us consider briefly some of the conditions that may be responsible for ocular vertigo. Every eye specialist has met with one or more cases of refraction trouble, where

among the several symptoms complained of was vertigo. Vertigo or dizziness is not an uncommon symptom experienced by patients when they begin to wear bifocals, the more so if they happen to be poorly adjusted. Frequently upon having them adjusted properly the vertigo disappears. The vertigo in this instance may be due to double vision or to an imbalance in the refraction of the two eyes, producing anisometropia, when, for instance, the glasses happen to be so poorly adjusted that the visual axis of one passes through the upper or distant glass, while that of the fellow-eye passes through the lower segment, or near glass. We occasionally find individuals wearing glasses thus out of plumb who do not complain of any unpleasant symptoms, while others complain bitterly of the contradictory visual impression (vertigo); but more especially do they complain of the sickness of the stomach (accompanying symptom of vertigo). The effect of putting an excessively plus or convex glass before the eyes produces an incorrect interpretation of external objects. The magnification produces the effect of nearness; the blurring of outlines the contrary effect of increased distance. Both are false perceptions—hence vertigo. The confusion is even more pronounced when the excessive plus glass is put before one eye only. More or less dizziness is complained of when a cycloplegic, like atropin, is put in one eye and not in the other, the more so if the patient has a fair degree of hyperopia, for reasons similar to those just cited. The same effect is produced by a sudden paralysis of the ciliary muscle from any other cause. The vertigo and the accompanying disagreeable symptoms produced by the conditions and experiments thus far cited are nothing as compared with those produced by extraocular disturbances. Take a case of sudden paralysis of one of the extrinsic eye muscles; for instance, a paralysis of the external rectus of the right eye; the result is a converging strabismus with diplopia. The patient sees every object double and does not know which to accept as the real one. He has vertigo and is

disorientated—may even lose his balance and walk broad and uncertain; while the accompanying symptoms are even more distressing.

The vertigo that results from a paralysis of one or more of the extraocular eye muscles disappears as soon as the patient learns to suppress the false image perceived by squinting the eye. He learns to close the affected eye and accepts only the image perceived by the normal one. With some individuals it may be a matter of only a few minutes; with others several days.

Paralysis of an extraocular muscle produces vertigo, as mentioned above, but the vertigo is not so lasting as in the case of paresis, for the reason that in paralysis the diplopia is a fixed quantity to which the patient sooner or later becomes accustomed; whereas in paresis the patient no sooner learns to accommodate himself to one amount of diplopia when it changes to another. It is ever shifting in degree. The best that he can do when he desires binocular single vision is to turn his head to that position least likely to produce diplopia; that is, toward the paretic muscle in order that his eyes may be turned in the opposite direction.

Paresis of a vertically acting muscle produces a greater degree of vertigo than paresis of a horizontally acting one. The writer is inclined to believe that the vertigo resulting from a paresis of one of the oblique muscles is even more intensive, but of that he is still uncertain because of the lack of sufficient observation.

(Abstracted from the *Journal of Ophthalmology*, *Otology* and *Laryngology*, Vol. XXV, p. 164, 1921.)

477

478

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